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for Plants and Production of
ARCHITECTURAL PRECAST CONCRETE PRODUCTS

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FOREWORD

This Manual has been prepared as a guideline for the manufacture and erection of quality architectural precast concrete. It is not intended to be a specification document, although many requirements normally covered by a specification have been included.

The first edition of the *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products* was prepared by the PCI Plant Certification Subcommittee for Plant Production of Architectural Precast Concrete Products. Subsequent to the publication and use of the first edition, a plant certification program was established for the precast prestressed concrete industry. The inspection of architectural precast concrete production facilities, carried out under this program, was based on the recommended practices and criteria outlined in that Manual. Experience by both the manufacturers and the inspection teams led to this latest revision, making this second edition even more representative of a high standard of industry practice.

The greatly expanded second edition was prepared under the direction of the following members of the PCI Plant Certification Subcommittee:

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INTRODUCTION

Architectural precast concrete products are those precast concrete units of custom-designed or occasionally standard shapes and sizes that, through either application, finish, shape, color or texture, contribute to the architectural effect of the structure. Not generally included are the so-called industrialized precast products (standard shapes), such as double or single tees, channel sections, and flat or hollow-core slabs. Architectural precast concrete units may be manufactured with conventional mild steel reinforcement, or they can be prestressed.

The most common use of architectural precast concrete is the precast wall panel. In addition to serving as load bearing or non-load bearing exterior or interior walls, precast panels may perform other functions. They may serve as formwork for cast-in-place concrete or as shear walls. They may serve partly or fully as enclosures for mechanical services, or they may combine several of these functions to become a wall sub-system, sometimes partially pre-assembled prior to reaching the site.

The manufacture of architectural precast concrete products requires a greater degree of craftsmanship than many other construction products. In addition, many combinations of shape, size, color and texture are demanded of this product. Thus, a uniform standard of quality is difficult both to establish and to control.

The recommendations of this Manual are intended to achieve optimum quality. This may be defined as the level of quality, in terms of appearance, strength and durability, which is appropriate for the specific product and its particular application.

Realistic cost estimates for producing it within stated limitations are necessary factors which must be considered in determining this level. In other words, it is that quality which is economical and suitable for a specific product and for the particular purpose it serves as a component in the overall building project.

While a minimum quality standard may be inferred, there is no intent to place a ceiling on excellence. The degree of success in specifying and obtaining optimum quality for precast concrete products will depend on the combined efforts of designers and manufacturers to define and coordinate their individual requirements and responsibilities.

Quality control begins when the architect determines shape, size, color and texture for the architectural precast concrete products for a specific project. These characteristics may then determine the methods of manufacture, as well as the handling and installation techniques. Consultation with qualified representatives of experienced manufacturers will be of great value in achieving high qualconcrete should be clearly stated in the final plans and specifications. They should be neither open to interpretation nor unnecessarily restrictive.

No manual of this type can be all-inclusive. The recommendations given herein are presented only as an outline of the more important factors governing the quality of architectural precast concrete. Their value is dependent on rational application and a determination on the part of individual producers to establish a standard of quality that will be recognized and respected by the general public. Furthermore, personnel in the manufacturer's and erector's organizations must be thoroughly trained and competent in order to achieve quality architectural precast concrete structures.

It is not the intention of this Manual to restrict individual plant techniques. For example, a manufacturer's methods for mixing, placement, consolidation and curing of concrete will be acceptable, provided these methods can consistently result in uniform and durable concrete of the specified quality.

The Commentary, Appendix D, contains suggestions and additional information of help in carrying out the requirements or intent of this Manual. However, the Commentary is not to be considered as part of this Manual in judging quality control procedures.

The Architect-Engineer is directed to Appendix A for a listing of subjects pertinent to his responsibilities which are to be considered in the preparation of plans and specifications for an architectural precast concrete project.

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DEFINITIONS

Accelerated curing—See Curing.

Admixture—A material other than water, aggregates, and cement used as an ingredient of concrete or grout to impart special characteristics.

Alignment face—Face of a wall panel which is to be set in alignment with the face of adjacent panels.

Ambient temperature—The temperature of the air surrounding the forms into which concrete is to be cast, or of the air surrounding an element during curing.

Architectural precast concrete—Any precast concrete unit of special or occasionally standard shape that through application or finish, shape, color, or texture contributes to the architectural form and finished effect of the structure; units may be structural or decorative, and may be conventionally reinforced or prestressed.

Backup mix—The concrete mix cast into the mold after the face mix has been placed and consolidated.

Bleeding—A form of segregation in which some of the water in a mix rises to the surface of freshly placed concrete; also known as water gain.

Bond breaker—A substance placed on a material to prevent it from bonding to the concrete, or between a face material such as natural stone and the concrete backup.

Bonding agent—A substance used to increase the bond between an existing piece of concrete and a subsequent application of concrete such as a patch.

Connections—Devices for the attachment of precast units to each other or to the building structure.

Covermeter—See R-meter.

Crazing—A network of fine cracks in random directions breaking the exposed face of a panel into areas of from 1/4 in. to 3 in. across. Some probable causes are rich cement mix, too early stripping, and inadequate curing.

Curing—The maintenance of humidity and temperature of freshly placed concrete during some definite period following placing, casting, or finishing to assure satisfactory hydration of the cementitious materials and proper hardening of the concrete;

mental range (generally between 50 F and 90 F) use the term normal curing; where the curing temperature is increased to a higher range (generally between 90 F and 150 F) use the term accelerated curing.

Draft—The slope of concrete surface in relation to the direction in which the precast element is withdrawn from the mold; it is provided to facilitate stripping with a minimum of mold breakdown.

Dunnage—Materials used for keeping concrete elements from touching each other or other materials during storage and transportation.

Face mix—The concrete at the exposed face of a concrete unit used for specific appearance reasons.

Form—See Mold.

Form release agent—A substance applied to the forms for the purpose of preventing bond between the form and the concrete cast in it.

Gap-graded concrete—A mix with one or a range of normal aggregate sizes eliminated, and/or with a heavier concentration of certain aggregate sizes over and above standard gradation limits; it is used to obtain a specific exposed aggregate finish.

Hardware—A collective term applied to items used in connecting precast units or attaching or accommodating adjacent materials or equipment. Hardware is normally divided into three categories:

Contractor's hardware—Items to be placed on or in the structure in order to receive the precast concrete units, e.g., anchor bolts, angles, or plates with suitable anchors.

Plant hardware—Items to be embedded in the concrete units themselves, either for connections and precast erector's work, or for other trades, such as mechanical, plumbing, glazing, miscellaneous iron, masonry, or roofing trades.

Erection hardware—All loose hardware necessary for the installation of the precast concrete units.

Homogeneous mix—A uniform concrete mix used throughout a precast concrete element.

Jig—A template to align parts of an assembly, usually for preassembling reinforcing steel and hardware cages, with a minimum of measurement to attain consistent accuracy from one cage to the next.

Laitance—Residue of weak and nondurable material consisting of cement, aggregate fines, or impurities brought to the surface of overwet concrete by the bleeding water.

Lifting frame (or beam)—A rigging device designed to provide two or more lifting points of a precast concrete element with predictable load distribution and pre-arranged direction of pulling force during lifting.

Master mold—A mold which allows a maximum number of casts per project; units cast in such molds need not be identical, provided the changes in the units can be simply accomplished as pre-engineered mold modifications.

Matrix—The portion of the concrete mix containing only the cement and fine aggregates (sand).

Mold—The container or surface against which fresh concrete is cast to give it a desired shape; sometimes used interchangeably with form but made of fiberglass or concrete; a pattern or positive is built first and the mold is overlayed. (The term is used in this Manual for custom made forms for specific jobs while forms are used for standard forms or forms of standard cross section.)

Pattern or positive—A replica of all or part of the precast element sometimes used for forming the molds in concrete or plastic.

Plastic cracking—Short cracks often varying in width along their length that occur in the surface of fresh concrete soon after it is placed and while it is still plastic; some probable causes of plastic cracking are high water-cement ratio, low sand content, and poor compaction.

R-meter—An electronic device used to locate and size reinforcement in hardened concrete.

Retarder—An admixture which delays the setting of cement paste and therefore of concrete.

Retarder, surface—A material used to retard or prevent the hardening of the cement paste on a concrete surface within a time period and to a depth to facilitate removal of this paste after the concrete element is otherwise cured (a method of producing exposed aggregate finish).

Retempering—The addition of water and remixing of concrete which has started to stiffen in order to make it more workable.

splayed from the main face or plane of view.

Reveal—Groove in a panel face generally used to create a desired architectural effect. The projection of the coarse aggregate from the matrix after exposure.

Rustication—A groove in a panel face for architectural appearance; also reveal.

Scabbing—A finish defect in which parts of the form face including release agent adhere to the concrete, some probable causes are an excessively rough form face, inadequate application of release agent, or delayed stripping.

Scouring—Irregular eroded areas or channels with exposed stone or sand particles; some probable causes of this finish defect are excessively wet concrete mix, insufficient fines, water in form when placing, poor vibration practices, and low temperature when placing.

Segregation—The tendency for the coarse particles to separate from the finer particles in handling; in concrete, the coarse aggregate and drier material remains behind and the mortar and wetter material flows ahead; this also occurs in a vertical direction when wet concrete is overvibrated or dropped vertically into the forms, the mortar and wetter material rising to the top; in aggregate, the coarse particles roll to the outside edges of the stockpile.

Set-up—The process of preparing molds or forms for casting, including installation of materials (reinforcement and hardware) prior to the actual placing of concrete.

Spreader beam—A frame of steel channels or beams attached to the back of a panel, prior to stripping, for the purpose of evenly distributing loads to inserts and for lifting the panel about its center of gravity.

Stripping—The process of removing a precast concrete element from the form in which it was cast.

Strongback—A steel or wooden plate which is attached to a panel for the purpose of adding stiffness during handling, shipping, and/or erection.

Tolerance—Specified permissible variation from stated requirements such as dimensions, strength, and air entrainment.

Workability—The ease with which a given set of materials can be mixed into concrete and subsequently handled, transported, placed, and finished with a minimum loss of homogeneity.

DIVISION I—QUALITY CONTROL PHILOSOPHY

Section 1—Objectives and Methods

1.1.1—General Objectives

A quality control manual sets forth the methods and means of producing quality architectural precast concrete units. Such a manual, no matter how thorough, will not of itself insure that acceptable products of uniform quality will result. One further requirement remains.

There must be a recognition by producers that uniform quality requires intelligent effort and continual faithfulness to detail in achieving proper design, proper materials and proper methods for forming, mixing, placing, curing, finishing, storing, transporting and erecting architectural precast concrete products. A qualified individual must be made responsible for each of these stages of operation and, having been made responsible, must be entrusted with the necessary authority to insure proper performance.

Over-all product quality will result from a dedicated total effort at all personnel levels. Each plant shall establish a program of quality control at all stages of design, production, inspection and erection, and require strict adherence to the program by all levels of personnel at all times.

1.1.2—Principal Factors in Quality Control

Many factors enter into the control of quality of architectural precast concrete units. The most important requirements for production control are:

(1) Qualified personnel responsible for all stages of design, production, inspection and erection.
(2) Adequate testing, inspection, and maintenance of records for all materials selected for use.
(3) Clear and complete shop (erection and production) drawings.
(4) Proper proportioning and adequate mixing of concrete.
(5) Control of dimensions and tolerances, including adequate mold construction.
(6) Proper bending, placement and securing of reinforcement.
(7) Suitable methods of attachment and proper location of all cast-in or hardware items.
(8) Proper handling, placing and consolidation of concrete.
(9) Suitable curing.
(10) Proper stripping procedures.
(11) Proper finishing procedures.

(13) Adequate inspection and checking of all operations and maintenance of necessary records.

1.1.3—Management Responsibilities

In order to achieve a satisfactory level of quality control, certain fundamental requirements shall be met by management, the more important being:

(1) Establish a standard of quality and insist on it being observed.

(2) Establish uniform practices that are constantly observed to obtain the following:
  (a) Concrete of a uniform quality batch after batch.
  (b) Placement and compaction of concrete that results in optimum consolidation.
  (c) Thorough curing for each unit.
  (d.) Handling and storage which results in the least disfiguration and distortion of the units.

(3) Wherever possible eliminate highly varied or special practices subject to human error or mistakes in judgment.

(4) Have every operation subject to inspection by personnel independent of production. These include set-up details, production and acceptance operations.

(5) Establish practical procedures for complete bed and mold set-ups which give rise to beds and molds which are easy to inspect and verify prior to start of concreting.

(6) Establish an acceptance inspection program by quality control personnel prior to storage in readiness for shipping.

(7) Establish uniform methods for reporting and keeping of records.

(8) Establish engineering operations to meet required codes, standards and specifications, and in-plant performance requirements.

Section 2—Personnel

1.2.1—General

In this section, the functional responsibilities of certain basic positions are outlined. Whether one or more of these functions is assigned to one person, or whether several persons are assigned to a specific function, is the prerogative of management and will depend on the purpose of the products and the size of plant. Regardless of the number of individuals, each plant shall have personnel qualified to perform the functions of the various positions outlined in this section.

1.2.2—Functional Responsibilities

Each plant should prepare, maintain and implement an organizational chart which clearly assigns responsibilities, and establishes the relationship between quality control, engineering and production.

(1) *Sales and Estimating.* Secure all contract documents, prepare accurate quantity takeoffs of all materials required for the project, and identify all quality requirements.

(2) *Engineering.* Plants shall have the services of a registered engineer experienced in the design of precast concrete. He shall prescribe design policies and be competent to review designs prepared by others. He shall be responsible for the structural design of all products designed by his staff and it is recommended he review designs prepared by independent designers (see Division II, Section 5).

In plants producing prestressed architectural precast concrete units, the engineer shall be responsible for prescribing or approving methods and procedures for stressing, computations and measurements for elongations, camber and deflections, compensations for operational stress variations and any other variables that may affect the quality of the product. The engineer shall review and shall be responsible for the structural implications of any drafting work executed by the plant.

The engineer shall have the ability to solve problems and devise methods as required for the design, production, handling and/or erection of architectural precast concrete products. Also, he shall approve the sequence of erection, when sequence may affect structural stability.

(3) *Drafting.* Plants shall have experienced personnel competent to prepare shop (production and erection) drawings in general accordance with the *PCI Architectural Precast Concrete Drafting Handbook.* Details should be of such clarity and completeness to reflect the contract documents in a manner that minimizes the possibility of errors during the manufacturing and erection processes. Drafting personnel should be responsible for conformance of drawings to the contract documents and precast manufacturer's standards.

(4) *Production.* Production personnel have the immediate re-

drawings, specifications and established plant standards. Production personnel shall be qualified to:

(a) Determine and specify methods, facilities and equipment for use in production.

(b) Schedule work to obtain the maximum utilization of facilities.

(c) Price and order materials, operating supplies and equipment as necessary to satisfy production schedules.

(d) Receive, check and store incoming materials and maintain adequate inventory control.

(e) Direct fabrication of reinforcement and molds in accordance with the production drawings, specifications, and production schedules.

Production shall produce units finished for shipment, as required by the production schedule, and in accordance with the contract documents and approved samples. Finished units shall be stored and loaded for shipment as required by erection sequence, weight and local shipping regulations. It is important to establish a program of preventative maintenance for tools, equipment, buildings and utilities to minimize production down-time and maintain their functional adequacy, value and appearance.

The production superintendent shall be responsible for the establishment and implementation of an adequate safety program in accordance with the *PCI Safety and Loss Prevention Manual.* In order to perform properly, he shall have a basic understanding of, and respect for, the various functions involved in engineering and quality control. He shall see that all methods prescribed by design and quality control are carefully followed and any necessary variations are referred to Engineering for information and approval. He shall insure that accurate records of all applicable phases of production are maintained.

(5) *Quality Control.* This function shall have direct lines of communication to engineering, production and management with responsibility only to management, and *shall not* be subject to control by production. Responsibilities shall include:

(a) Inspection and verification of the accuracy of dimensions of units, quantity and location of reinforcement and cast-in items, form and mold layout, and other matters pertaining specifically to production. Checking adequacy of the form to produce units without undesirable distortion or surface defects.

(b) Inspection and observation of all stressing operations (if applicable) to insure that specified procedures are used.

(c) Periodic inspection of concrete batching, mixing, handling, placing, consolidating, finishing and product handling and storage procedures.

(d) Checking propriety of materials and mixtures as developed by an outside testing laboratory, or proportioning a mix, evaluating it in relation to both design and production requirements, and, if necessary, modifying it to obtain the end product desired. This includes consideration of strength, durability and appearance.

(e) Source of information and assistance relative to evaluation of new products for use in production or erection.

(f) Fabrication of representative test samples and testing as described in Division II, Section 1.

(g) Inspection of all finished products for conformance with shop drawings and specifications. This conformance must be within specified tolerances that are applicable to each product or at least within the limits of listed industry standards.

(h) Appearance inspection as necessary to ensure that units have a uniform finish and match the appearance of the approved project samples.

(i) Preparation and maintenance of complete quality control records for all products. These records shall include all information pertaining to the production of each unit and will provide a means by which a unit may be identified.

(6) *Erection.* Erection supervisors shall be qualified to direct all operations involving handling, transporting and erecting precast concrete with special emphasis on the following:

(a) Make sure units are handled and supported at specified points only and by approved devices.

(b) During transportation, insure units are adequately supported and braced so they are not subjected to excessive stresses from dynamic and lateral forces.

(c) Coordinate the arrival of the units at the jobsite.

(d) Insure units are properly handled and stored at the jobsite, with special attention being given to unyielding supports at the proper points.

(e) Supervise erection, as required, to insure units are proper erection sequence. Give consideration to limits of available access and equipment and coordination with other trades. Check erected units to verify adequate bearing, suitable connections, proper bracing and conformance with tolerances as outlined by specifications and/or industry standards.

DIVISION II—PRODUCT CONTROL

Section 1—Testing

2.1.1—General

Testing is an integral part of the total quality control program. It is necessary for internal plant quality control as well as quality control of the precast concrete unit. Testing must be directed towards maintaining a uniform level of plant standards. Testing for quality control of the precast concrete unit must follow plant standards as well as standards required by the specifications for a particular project.

For control of concrete, testing of specimens, and the design and control of concrete mixes, each precast concrete plant shall (1) be equipped with adequate testing equipment and staffed with personnel trained in its use, or (2) if the plant has contracted for quality control to be performed by an outside concrete laboratory, that laboratory shall have been inspected within 2 years by the Cement and Concrete Reference Laboratory of the National Bureau of Standards, and meet the requirements of ASTM E 329.*

2.1.2—Acceptance Testing of Materials

The specified properties of all materials used in the manufacture of precast concrete products shall be determined by appropriate testing in conformance with appropriate ASTM procedures, by either the supplier or the precast manufacturer.

Suppliers of materials shall be required to furnish certified test reports for cement, aggregates, admixtures, curing materials, reinforcing and prestressing steel, and hardware materials, indicating that these materials comply with the applicable plant standards and project specifications.

In some instances, materials may not conform to nationally recognized specifications but may have a long history of satisfactory performance. Such nonconforming materials are permitted with special approval of the Architect-Engineer when acceptable evidence of satisfactory performance is provided.

(1) *Cement.* Plant testing of cement shall not be considered necessary if mill certificates are supplied with each shipment. All cement shall meet the requirements of the specified Type in ASTM C 150 or C 595. Mill certificates of cement shall be kept on file in the plant for at least 2 years after cement use. It is good practice to keep a 10-lb. sample of cement in an air-tight container for a period of 6 months

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* Titles for all standards and other documents referred to in the Manual are given in Appendix B.

Characteristics of special and colored cements should be investigated prior to use to be certain that they do not exhibit undesirable attributes of high slump loss, strength retrogression, plateau-strength or other aberrations under variable environmental conditions of casting and curing.

(2) *Aggregates.* Aggregates shall be thoroughly evaluated for the environmental conditions to which they will be exposed. Fine and coarse aggregates shall be regarded as separate ingredients.

Aggregates shall conform to ASTM C 33 or C 330. The grading requirements (only) of these specifications are generally waived or modified because of special requirements of gap-graded face mixes and the advantages in having backup mixes as consistent as possible with face mixes. Sieve analysis in accordance with ASTM C 136 shall be conducted upon delivery, prior to start of aggregate use. Specific gravity, absorption, alkali aggregate reactivity and petrographic analaysis test results shall be obtained from the supplier at least one month prior to the time of first usage and verified semi-annually or when new mining or quarrying deposits are utilized. Producers of glass aggregates shall guarantee low reactivity of their materials with portland cement.

Occasionally coarse aggregates may contain particles with an iron oxide content that results in unsightly stains. This generally becomes noticeable at a later date due to oxidation from exposure to the atmosphere. Since this aggregate could meet the staining requirements of ASTM C 330, the requirements should be tightened so that aggregates tested by ASTM C 561 show a stain index less than 20. An additional quick test is described in Appendix D.

For exposed concrete in cold climates, the magnesium sulfate soundness loss (ASTM C 88) should be less than 8 percent unless at least 5 years of historical experience under similar environmental use indicates suitable durability.

Deleterious substances in aggregates shall be limited to the allowances given in ASTM C 33 for exposed architectural concrete located in severe weathering regions with one exception—fine aggregate shall not exhibit a color darker than Organic Plate 1 when tested for organic impurities in accordance with ASTM C 40.

(3) *Water.* Water shall be chemically analyzed when a private well or non-potable water is used in the concrete mixing.

Except for water from a municipal supply, analysis of the water shall be on file in the plant and be updated every 6 months and be clearly related to the water in use. Water of unknown quality may be considered acceptable if it produces mortar cubes having 7- and 28-day strengths equal to at least 90 percent of the strength of similar specimens made with water from a municipal supply. The strength comparison shall be made on mortars, identical except for the mixing water, prepared and tested in accordance with ASTM C 109.

(4) *Reinforcing Steel and Prestressing Materials.* Plant testing of reinforcing steel or prestressing materials shall not be required if mill certificates are supplied. Mill certificates of reinforcing steel and prestressing materials in stock or in use, indicating that they meet the requirements of applicable ASTM specifications and ACI 318, shall be kept on file in the plant for at least 2 years after use. Certificates shall be requested for each size and shipment and for each grade of steel. Certificates shall be requested for each ten reels or coils of prestressing strand or wire in each size, and for each heat or at least for each shipment if less than ten reels or coils. Certificates for prestressing bars shall be kept on file for each size, 10-ton shipment, each heat, or each shipment if less than 10 tons. Incoming steel, wire and strand shall be examined for excessive scaling or pitting.

If it is desired to restrict the range in the chemical composition of steel to provide satisfactory weldability, conformance with these supplemental requirements shall be certified in writing by the supplier.

The typical stress-strain curve of the prestressing steel shall be on record. An actual curve representing the production lot from which the project material was taken may be required to verify its compliance with the typical curve.

(5) *Admixtures.* All relevant admixture information with respect to performance, quantities, and application methods shall be on file at the plant. Air-entraining admixtures shall conform to the requirements of ASTM C 260. Other admixtures shall conform to the requirements of ASTM C 494, Types A, B and D. The supplier shall certify these admixtures do not contain calcium chloride in excess of 0.1 percent. Fly ash or other pozzolans used as admixtures shall conform to ASTM C 618.

(6) *Pigments and Pigmented Admixtures.* The supplier shall certify that pigments or other coloring agents are resistant to lime and other alkalies. Tests for lime resistivity are de-

of the coloring agents and their effects on air content, water requirements of concrete mix and concrete strength shall be evaluated prior to making final selection of coloring agent. Synthetic mineral oxide pigments may react chemically with other products used on the surface, such as surface retarders or muriatic acid, and should be tested for these reactions prior to use.

(7) *Hardware and Inserts.* Plant tests shall not be required for hardware but mill certificates shall be obtained for mild steel materials and each different grade of steel. Inserts need not be plant tested if used only as recommended by the suppliers and within their stated (certified) capacities and application qualifications. Records shall be on file, however, establishing working capacity of each kind and size of inserts used for handling and/or connection.

(8) *Curing Compounds, Form Release Agents, Surface Retarders and Weatherproofing Sealers.* Information shall be requested from suppliers and kept at the plant for all such materials used in the plant along with procedures for their proper use and application. Before using these materials in a production run, they shall be tested with the project design mix under simulated production conditions to verify that the materials perform satisfactorily. If membrane curing compounds are used to retain moisture in concrete, such materials shall conform to ASTM C 309; if sheet materials are used they shall conform to ASTM C 171.

(9) *Concrete Mixtures.* Concrete mix proportions should be established under carefully controlled laboratory conditions. Casting of a mix in a critical part of an actual mold is often advisable for checking a mix under production conditions. Representative cylinders also shall be cast and cured under plant production conditions for lightweight concrete mixes to demonstrate the strength and weight of the concrete produced. All concrete mixes shall be developed using the brand and type of cement, the type and gradation of aggregates, and the type of admixture proposed for use in production mixes. If at any time these variables are changed, the mix shall be re-evaluated. This re-evaluation may include one or more of the following concrete properties:
(a) Color, surface texture, or aggregate exposure.
(b) Air content or durability.
(c) Strength (selected tests at appropriate ages).

Records of all concrete mixes used in a plant and their respective test results shall be on file. Acceptance tests for concrete mixes must include:

(a) Compressive Strength. Standard test specimens (6 x 12-in. or 4 x 8-in. cylinders or 4-in. cubes) shall be made and cured in accordance with ASTM C 192 and tested in accordance with ASTM C 39. Test specimens using 4-in. cubes are permitted providing proper and proven correlation with the standard 6 x 12-in. test cylinder is available. The 28-day design strength established for facing mixes and backup concrete shall be not less than 5000 psi. Design requirements may dictate higher strength. In addition to the 28-day tests, compression tests shall be made at the anticipated time for stripping the production unit from the mold to determine if mix design modifications are necessary and to verify the strengths assumed in determining reinforcing steel requirements.

(b) Absorption. The procedure for water absorption determination of the proposed facing mixes is described in Appendix D. The maximum water absorption for normal weight concrete (150 lbs. per cu. ft.) at 28 days, shall not exceed 14 percent by volume. Alternatively, absorption expressed by weight shall not exceed 6 percent. The absorption of the facing mix of a continuous production run shall be verified every 6 months, for each new project, and whenever the materials and/or production methods are modified.

(c) Slump. Slump tests shall be made in accordance with ASTM C 143. The standard slump test may be inadequate as a measure of the workability of concretes with high proportions of coarse aggregate. A better measure of consistency for such concrete is by the Vebe consistometer. This test is described in Appendix D.

(d) Unit Weight. Unit weight shall be tested in accordance with ASTM C 138 or C 567.

(e) Air Content. For most architectural facing mixes it may be impractical to entrain a specific air content due to gradation or special consolidation requirements. Instead, the use of an air-entraining agent to provide a "normal" dosage is recommended. Normal dosage of air-entraining agent shall produce an 8 to 10 percent air content when tested in accordance with ASTM C 185, but using only the mortar (material less than ¼ in.) portion of the mix. The addition of normal the frost resistance of the concrete even though only a small amount of air is usually entrained.

Air content in concrete shall be measured in accordance with ASTM C 173 or C 231 as applicable. The volumetric method (ASTM C 173) may be used on any type of aggregate, whether it be dense, cellular or lightweight. The pressure method (ASTM C 231) gives excellent results when used with concrete made with relatively dense natural aggregates for which an aggregate correction factor can be determined satisfactorily. It is not recommended for use on concretes made with lightweight aggregates, air-cooled blast furnace slag, or aggregates of high porosity. It also may not work properly on very harsh or low-slump mixtures.

2.1.3—Production Testing

This type of testing is directed towards maintaining production uniformity by routine testing of materials and concrete to ensure that they are consistent with supplier's reported data or established requirements.

(1) *Aggregates.* A sieve analysis (ASTM C 136) shall be conducted in the plant with test samples taken at any point between and including stockpile and batching equipment. Such tests shall be carried out for each aggregate type and size at least once every 2 weeks or for each of the following aggregate volumes, where usage in a 2-week period exceeds such volume:

(a) Aggregates used in architectural face mixes	40 cu. yds.
(b) Fine aggregates used for backup mixes	200 cu. yds.
(c) Coarse aggregates used for backup mixes	400 cu. yds.

Surface moisture in aggregates shall be evaluated and continuously compensated for in all concrete proportioning. Moisture content may be determined in accordance with ASTM C 566. However, this method is time consuming and not necessarily accurate for practical concrete proportioning as it tests only an isolated sample. One alternate method in general use is a moisture meter that measures moisture by the pressure of chemically generated gas.

Continuous moisture determination by electric moisture meters is also satisfactory provided it is calibrated against the drying method (ASTM C 566). If moisture meters are not used, the free moisture shall be determined at least twice a day, or at any time a change of moisture content becomes obvious.

(2) *Concrete Strength.* Concrete shall be sampled and specimens made in accordance with the following specifications except as modified herein:

ASTM C 172—Sampling Fresh Concrete.

ASTM C 31—Making and Curing Concrete Test Specimens in the Field.

The size of specimens made and cured in accordance with ASTM C 31 are modified to permit use of either 6 x 12-in. or 4 x 8-in. test cylinders or 4-in. cubes. Test specimens using 4-in. cubes shall be considered acceptable, provided that proper correlation with the standard test cylinders is available.

Maximum size of aggregate in 4 x 8-in. cylinder or 4-in. cubes should not exceed 1 in. If larger sized aggregate is contained in the concrete, the compressive strength should be measured using standard 6 x 12-in. cylinders. Special cube sizes may be used when they more adequately represent particular products, provided that strength correlation to standard 6 x 12-in. cylinders can be demonstrated.

Four compression specimens shall be made daily for each individual concrete mix (whether facing or backup mix), or for each 40 cu. yds. of any one mix where the daily consumption exceeds this volume. Two specimens should be used to determine the stripping strength, particularly if the mix is new and its history not well known. However, one specimen may be sufficient as production progresses. For face mixes, the specimens normally required for determining stripping strength may be omitted when the ambient air temperature is higher than 50 F.

Cylinder molds shall be kept clean and free from deformations. Any molds that become distorted, or which do not comply with the dimensional requirements of ASTM specifications, shall be discarded.

Test specimens shall be made as near as possible to the location where they will be cured and shall not be disturbed in any way from ½ hour after casting until they are either ready to be stripped or tested. Specimens should be protected from rough handling at all ages.

Test specimens shall be cured with and by the same methods as the units they represent up to the time of stripping mens shall be removed from their molds and placed in a moist condition at 73.4 F ± 3 F.

Unless specimen ends are cast to within 0.002 in. of a plane surface, they shall be capped prior to testing. Capping procedures shall be as specified in ASTM C 617 except when fast setting sulfur compounds, especially manufactured for capping, are used. Compression testing may be performed ½ hr. after the caps have been in place. The casting temperature of capping compounds is critical. Thermostatically controlled heating pots shall be used.

Testing of specimens to determine compressive strength shall be performed in accordance with ASTM C 39. The strength of concrete at any given age shall be determined as the average of two specimens except one specimen can be used to determine stripping strength.

Impact tests shall be made in accordance with ASTM C 805 except as modified in Appendix D. An impact test using the Swiss (Schmidt) hammer is a useful tool to supplement compressive tests, but sometimes produces unreliable readings at early ages (stripping time) and should not supplant compressive tests.

An impact test on a concrete unit shall consist of at least three sets of readings (test areas) taken along the unit. Sixteen readings shall be taken in a test area. The three high and the three low readings shall be discarded and the average reading for the area computed from the remaining ten. The rebound number is considered reliable when the 10 readings do not deviate more than ±2½ to 3½ on the scale. Whenever possible, the readings representing one test should be confined to an area of about 1 sq. ft.

The test position should be 2 in. or more from the edge of the concrete or low readings will result. A repeated test on the same spot or near it will result in lower readings due presumably to local partial crushing of the concrete.

The compressive strength for concrete in the area shall be taken from the point on the calibration curve corresponding to the average reading; and the strength of the unit shall be taken as the average of the strengths indicated at the three areas.

If the compressive strength of a unit is questionable because of test results (Article 5.5.1), at least three cores shall be taken from each unit considered potentially deficient. Test cores shall be obtained, prepared and tested in accordance with ASTM C 42. Concrete in the unit represented by the core tests shall be considered structurally adequate if the average strength of three cores is equal to at least 85 percent of the specified strength and if no single core is less than 75 percent of specified strength.

(3) *Slump.* Slump tests for each concrete mix design shall be made at the start of operations each day, when making strength test specimens, and whenever consistency of concrete appears to vary.

A tolerance of up to 1 in. above the maximum specified slump may be allowed for individual batches provided the slump variation does not affect appearance or other qualities of the concrete beyond that allowed in the specifications. Concrete of lower than usual slump may be used provided it can be properly placed and consolidated.

(4) *Air Content.* Air content of air-entrained concrete shall be tested periodically during the daily operation with a minimum of one daily check per mix design or when making strength test specimens.

Variations from the established value of air content should not exceed ±1.5 percentage points to avoid adverse effects on compressive strength, workability, or durability.

A check on the air content should be made when the slump varies more than ±1 in., temperature of the concrete varies more than ±10 F, finishing difficulties develop, bleeding appears, a change in aggregate grading occurs, or there is a loss in concrete yield.

(5) *Unit Weight.* Unit weight tests of backup concrete shall be carried out at least once per week for each mix design used regularly except for lightweight concrete which shall be tested daily.

(6) *Temperature of Concrete.* Temperature of plastic concrete shall be recorded when strength tests are made, at frequent intervals in hot or cold weather conditions, and at start of operations each day. An armored thermometer accurate to ± 2 F should remain in the sample until the reading becomes stable.

(7) *Air Temperature.* When applicable, air temperature shall be recorded and correction made in stressing of tendons, if necessary. Refer to PCI MNL 116, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products,* for procedure.

2.1.4—Special Testing

(1) *Heat of Hydration.* When massive castings, or castings in partly insulated molds are being made, an excessive heat

warpage or excessive shrinkage of the casting. When such castings are being produced, the temperature history of one typical casting should be recorded by self-recording thermometers and, if over 150 F, steps must be taken in all castings to cool the concrete.

(2) *Concrete Coverage of Reinforcing Steel.* When concrete cover is minimal, products stored in the yard should be tested on a periodic basis for proper concrete coverage over reinforcing steel. It is suggested that one out of every 20 panels be tested and marked as a test panel. However, the frequency of such tests will depend on other production and control procedures.

(3) *Freeze-Thaw Tests.* If, due to special environmental conditions, freeze-thaw tests are deemed desirable, the test conditions of freezing in air, thawing in water (ASTM C 666, Method B) should be followed. Under this test method, a minimum allowable durability factor of 70 is recommended. These tests take several months to complete. Equivalent evaluations can be obtained more rapidly by conducting "air void studies" (amount and character of entrained air in cores taken from the production unit) in accordance with ASTM C 457.

Section 2—Inspection and Records

2.2.1—Necessity for Inspection

Specifications and plant standards can prescribe and explain proper methods for all phases of production consistent with products of highest quality. To insure these methods are being followed, inspecting personnel and a regular program of inspecting all aspects of production shall be provided in all plants. Inspectors shall be responsible for quality only and should not be responsible for or primarily concerned with production.

Inspection operations shall be so managed that production is not delayed as long as specified procedures are being followed. Every effort toward cooperation shall be observed between production personnel and inspecting personnel.

2.2.2—Scope of Quality Control Inspection

In general, the scope of quality control inspections to be performed in architectural precast concrete plants shall include, but not necessarily be limited to the following:

(1) Any required plant testing of materials for acceptance

prior to initial casting, and daily check testing for quality maintenance.

(2) Mix design for all concrete and all required concrete testing.

(3) Inspection of forms, and new set-up changes, as a second check on set-up personnel.

(4) Checking of blockout positioning, sealing strips, rustication strips, cast-in items; position and amount of reinforcement and any other critical tolerance items, and proper securing of these items during placing of concrete.

(5) Checking of molds and appurtenances for maintenance of tightness, dimensions and general quality with continued use.

(6) Periodic detailed inspection of batching, mixing, conveying, placing, compacting, curing and finishing of concrete.

(7) Periodic inspection of stripping from mold.

(8) General observation of plant, equipment, working conditions, weather and other items affecting production.

(9) Preparation of concrete specimens for testing and performing of tests for slump, air content, compressive strength, and other concrete tests.

(10) Inspection of architectural finish to make sure that the product matches the standard established by the approved project mockup or sample in color, texture, and uniformity. Finish defects and other problems shall be reported and a decision made as to acceptance, repairs, or manufacturing change. Units which are damaged are to be recorded and marked.

(11) Check finished product against approved shop drawings to ensure that proper finishes are on all required areas, panel measurements are correct, cast-in items are correctly located, panel is properly identified and marked, and that all critical measurements are within allowable tolerances. These checkups sound routine, but their importance cannot be emphasized enough.

(12) General observations of storage area for proper blocking, methods for prevention of chippage, warpage, cracking, contamination or blocking stains, and any other items that may adversely affect the quality of the product.

(13) Final inspection of product during loading for proper blocking and to detect stains, chips, cracks, warpage or other defects. Material and units for each project should be thoroughly checked in accordance with the above, prior to and during initial production; thereafter, spot checks

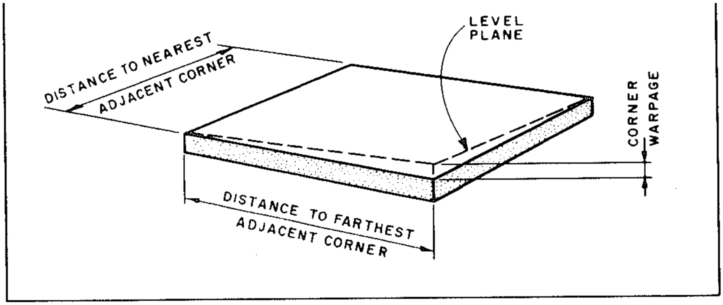

LEVEL PLANE
DISTANCE TO NEAREST ADJACENT CORNER
DISTANCE TO FARTHEST ADJACENT CORNER
CORNER WARPAGE

Fig. 1. Warpage of one corner of panel

face of each panel which is exposed to view after erection complies with the following dimensional requirements:

(1) *Warpage.* Maximum permissible warpage of one corner out of the plane of the other three shall be 1/16 in. per ft. distance from the nearest adjacent corner. This requirement is illustrated in Fig. 1.

(2) *Bowing.* Concave or convex bowing of any part of a flat surface shall not exceed length of bow/360 with a maximum of 3/4 in.; differential bowing or camber between adjacent members of the same design shall not exceed 1/4 in. The bowing requirement is illustrated in Fig. 2.

Slender panels should not be subjected to the standard tolerances for bowing and warping. Table 1 gives width and length dimensions in relation to panel thicknesses, below which bowing and warpage tolerances should be reviewed for each individual project. For slender panels below the range shown in Table 1, or for panels

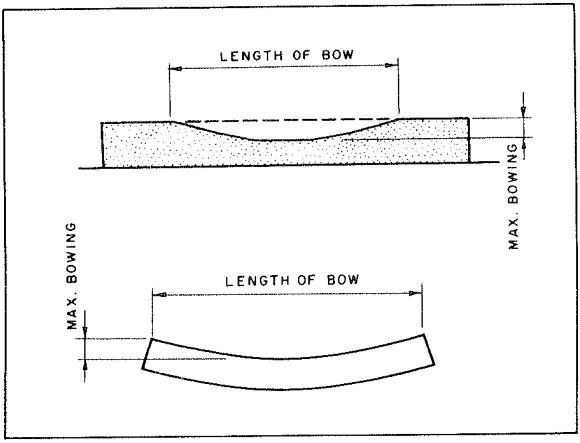


Fig. 2. Measuring of bowing in panel

Table 1. Typical panel thicknesses below which bowing and warpage tolerances should be re-assessed

Panel Dimensions	8′	10′	12′	16′	20′	24′	28′	32′
4′	3″	4″	4″	5″	5″	6″	6″	7″
6′	3″	4″	4″	5″	6″	6″	6″	7″
8′	4″	5″	5″	6″	6″	7″	7″	8″
10′	5″	5″	6″	6″	7″	7″	8″	8″

This table represents a relationship between overall flat panel dimensions and thicknesses below which suggested bowing and warpage tolerances should be reviewed and possibly increased. For ribbed panels, the equivalent thickness should be the overall thickness of such ribs if continuous from one end of the panel to the other.

with large aggregates (above $\frac{3}{4}$ in.), these tolerances should be increased.

Tolerances for units which are not homogeneous—consisting either of two widely different concrete mixes or natural stone veneer with concrete backup—should be specifically reviewed and may also have to be increased. The major criteria for maintaining or relaxing warping tolerances will be connection details (types and spacing), appearance requirements, and the advice of precasters for feasibility.

(3) *Alignment of Ribbed Members.* Deviation from straight lines parallel to centerline(s) of panel and/or designated skew:

Up to 40-ft. lengths	$\frac{3}{16}$ in.
40-ft. to 60-ft. lengths	$\frac{1}{4}$ in.

(4) *Dimensional Tolerances for Flat and Vertical Ribbed Wall Panels.* The location of these tolerances is shown in Fig. 3.

(a) Overall height and width measured at face adjacent to mold at time of casting or neutral axis of ribbed members:

10 ft. or under	$\pm\frac{1}{8}$ in.
10 ft. to 20 ft.	$+\frac{1}{8}$ in. $-\frac{3}{16}$ in.
20 ft. to 30 ft.	$+\frac{1}{8}$ in. $-\frac{1}{4}$ in.
Each additional 10 ft.	$\pm\frac{1}{16}$ in. per 10 ft. or $\pm\frac{1}{4}$ in. whichever is greater

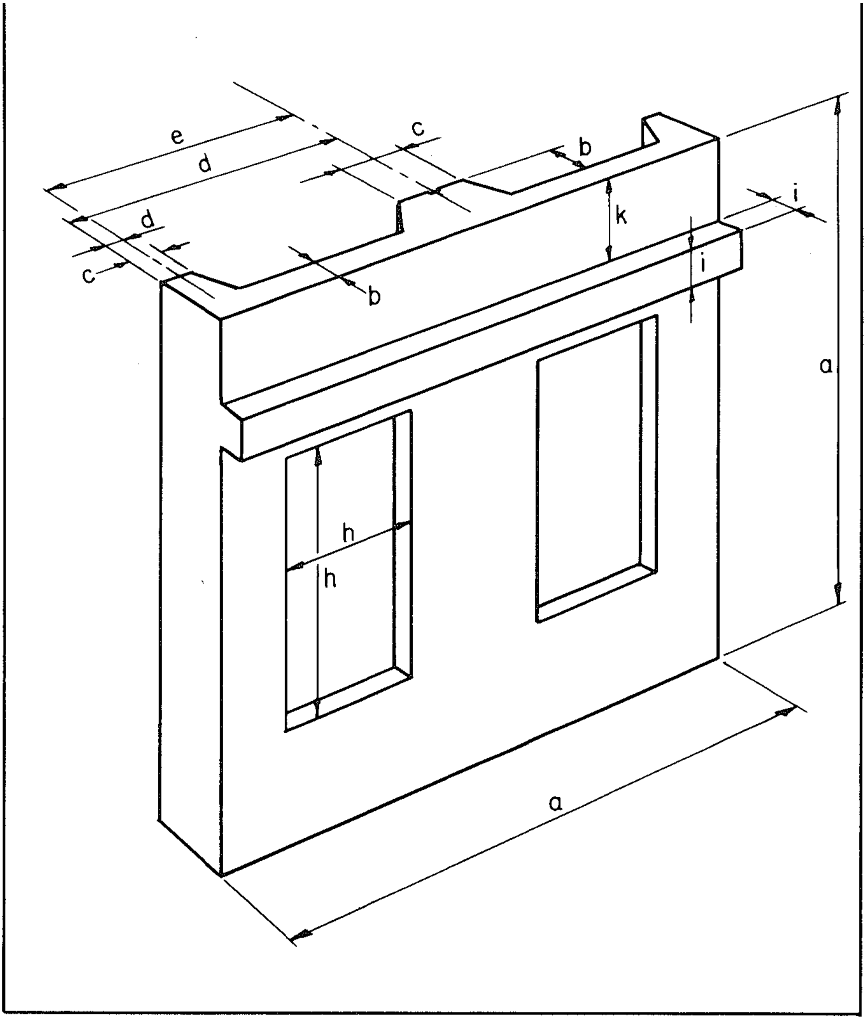


Fig. 3. Location of tolerances in a panel

(b)	Thickness—total or flange thickness	+¼ in. −⅛ in.
(c)	Rib thickness	±⅛ in.
(d)	Rib to edge of flange	±⅛ in.
(e)	Distance between ribs	±⅛ in.
(f)	Angular deviation of plane of side mold	$\frac{1}{32}$ in. per 3 in. of depth or $\frac{1}{16}$ in. total, whichever is greater

(g)	Deviation from square or designated skew (difference in length of the two diagonal measurements)	⅛ in. per 6 ft. or ¼ in. total, whichever is greater
(h)	Length and width of blockouts and openings with one unit	±¼ in.
(i)	Dimensions of haunches	±¼ in.
(j)	Haunch bearing surface deviation from specified plane	⅛ in.
(k)	Difference in relative position of adjacent haunch bearing surfaces from specified relative position	¼ in.
(l)	Tolerances on any dimension not specified above	the numerically greater of ±1/16 in. per 10 ft. or ±⅛ in.

(5) *Position Tolerances.* For cast-in items measured from datum line locations as shown on the approved erection drawings—weld plates shall be within 1 in. and inserts shall be within ½ in. of centerline location as shown on drawings, and handling devices within 3 in. Groups of inserts or cast-in items which must be located in close tolerance to each other should not be separated into two panels by a joint.

Reinforcing steel and welded wire fabric shall be within ¼ in. of the position as shown on the drawings, where such positions have structural implications or affect concrete cover; otherwise they shall be within ±½ in. Tendons shall be placed with a tolerance of ±⅛ in.

Cast-in grooves, reglets, or lugs that receive glazing gaskets should be held relatively close to their correct location. Misalignment of these reglets at corners, or casting these in a warped or "racked" position, will restrict proper installation of the glazing gasket. In addition, gasket manufacturers place severe restrictive tolerances on the groove width and surface smoothness necessary to obtain a proper moisture seal of the gasket.

Flashing reglets	±¼ in.
Flashing reglets, at edge of panel	±⅛ in.
Reglets for glazing gaskets	±1/16 in.
Groove width for glazing gaskets	±1/16 in.
Electrical outlets, hose bibs, etc.	±½ in.
Openings and blockouts	±¼ in.

require openings more accurately placed and, when this is the case, the minimum practical tolerance is .... ±⅛ in.

Haunches .... ±¼ in.

2.3.2—Product Finish

Since visual examination nearly always evaluates uniformity of color and intensity of shading, these are generally a matter of individual judgment and interpretation. At the time the sample, mockup or initial production units are approved, the acceptable variations in color, texture and uniformity shall be determined.

Accordingly, it is beyond the scope of this Manual to establish precise or definitive rules of measurement of acceptability. However, a suitable criteria for acceptability requires that the finished concrete surface shall present a pleasing appearance with minimal color and texture variations equal to the approved sample when viewed in good typical lighting with the naked eye at a 10-ft. distance and shall show no obvious imperfections other than minimal color and texture variations at a 20-ft. distance.

The following is a list of finish defects and/or problems which are normally unacceptable in high quality architectural precast concrete:

(1) Ragged or irregular edges.
(2) Excessive air voids—commonly called bugholes—evident on the exposed surface.
(3) Adjacent flat and return surfaces with a greater difference in exposure than the approved samples.
(4) Casting lines evident from different placements.
(5) Visible form joints or irregular surfaces.
(6) Rust stains on panel surfaces.
(7) Panels not matching approved sample or non-uniformity of color within a panel or in adjacent panels due to areas of variable aggregate concentration and variations in depth of exposure.
(8) Blocking stains or acid stains evident on panel surface.
(9) Non-uniformity of textures or color.
(10) Areas of backup concrete bleeding through the facing concrete.
(11) Foreign material embedded in the face.
(12) Visible repairs.
(13) Reinforcement shadow lines.
(14) Visible cracks.

Section 4—Damage and Repair

2.4.1—Repairs at Plant

A certain amount of repair of product is to be expected as a routine procedure. Repair work is an art requiring expert craftsmanship, if the end result is to be structurally sound, durable and pleasing in appearance. Gross variation in color and texture of repairs from the surrounding surfaces may be cause for rejection and request for replacement of the member. Major repairs should not be attempted until an engineering evaluation is made to determine whether the unit will be structurally sound.

Since the techniques and procedures of repairing architectural concrete are affected by a variety of factors including mix ingredients, final finish, size and location of damaged area, temperature conditions, age of panel, surface texture, etc., precise methods of repairing cannot be detailed in this Manual.

Adequate curing methods must be implemented as soon as possible to ensure that the repair does not dry out too quickly and cause it to shrink away from the existing concrete. Moist curing the repair area for a minimum of 3 days is most effective when possible.

Touch-up of all exposed galvanized metals cast in the precast units and affected by acid washing shall be done utilizing a 3-mil thickness of a single component zinc-rich compound with 95 percent pure zinc in the dried film. This touch-up work is to be done only at the completion of all intended curing and cleaning.

If cracking has occurred, and if repair is required for the restoration of structural integrity or esthetics, the cracks may be repaired by the injection of a low viscosity, 100 percent solids epoxy under pressure. Care should be taken to select an epoxy color (amber, white or gray) which most closely matches the concrete surface.

All repaired products shall be inspected by quality control personnel to ensure that proper repair procedures including curing have been followed and that the results are acceptable. Repairs should be evaluated when concrete surface is dry.

2.4.2—Repairs at Project

Architectural precast elements may be superficially damaged (minor chipping and spalling) during transport or erection and jobsite repair will be necessary. All major damage shall be reported to the Architect-Engineer for advice with respect to repairs. Decisions on rejection of panels should only be made with all interested parties present. Personnel from the precast concrete plant

A workman experienced in such jobsite repair should do the work. Repairs should be done only when conditions exist which assure that the repaired area will conform to the balance of the work with respect to appearance, strength and durability.

It is important that all repair of damaged panels be carried out well in advance of the joint sealing operation. The repair work must be fully cured, clean, and dry prior to caulking.

Section 5—Design

2.5.1—Design Considerations and Responsibilities

Design should take account of production realities relative to drafts, transitions and demarcation features.

In defining the shape of a panel, consideration must be given to the draft required to strip the precast unit from the mold as well as the draft required to achieve a specific finish (see Article 5.2.1). The greater the draft, the better will be the uniformity of the finish, so a compromise may have to be established between the finishing requirements and shape design of a precast unit.

The transition from one mass of concrete to another within a precast unit is a prime consideration. Wherever possible, the transition should be gradual, such as a large radius or fillet in the transition of a mullion to a flat portion in the unit. This is necessary to reduce the possibility of cracking and will enhance the structural integrity and the finish of the precast unit. Where a reasonable transition is not possible, a concrete mix with low shrinkage characteristics (low water and cement content) becomes increasingly more important. Alternatively, the transition may be accomplished with two-stage precasting.

When a precast unit has two different mixes, or in most cases when it has two different finishes, a demarcation feature is a necessary part of the design. The groove should be a minimum of ½ in. wide and ¾ in. deep. If a demarcation groove occurs near a change of section, it may create a weakness and counter any attempt to provide a gradual transition from one mass to another.

The manufacturer shall be responsible for translating the project requirements into samples, shop drawings, tooling, manufacturing and installation procedures. The aim is to insure the finished job shall match the specified quality, which may include the acceptable variances of the end product in place.

The manufacturer shall review the design of the precast concrete products with respect to finishes, connections, handling stresses, material quality, joint treatment, and tolerances for both manufacturing and installation. The manufacturer should report any variances to the Architect-Engineer (preferably prior to bidding). He may request approval for suggested modifications that could improve the design quality or structural soundness of the precast installation.

From the time shop drawings and finishes are approved for production, the manufacturer shall be responsible for plant casting, handling, delivery, and satisfactory installation (in some cases, others assume responsibility for erection) of the precast units. The manufacturer shall analyze all precast units for handling or temporary loadings imposed on them prior to and during final incorporation into the finished building or structure. He shall design and provide reinforcement or temporary strengthening of the units to insure that no stresses are introduced which will exceed the limitations of codes or standards governing the project, or have an adverse effect on their performance or safety after installation. Since stresses during handling and erection often govern the design of precast units, the manufacturer may incur design responsibility for these stresses.

After the precast units have been installed in the structure in conformance with plans and specifications, and accepted by the Architect-Engineer, subsequent responsibility and liability shall rest with the General Contractor and the Architect-Engineer. Provisions for any construction loads which are in excess of stated design requirements, and which may occur after installation of the units, are not the responsibility of the manufacturer, but are instead the General Contractor's responsibility.

2.5.2—Shop Drawings

The primary function of precast shop (erection and production) drawings is the translation of contract documents into usable information for manufacture, handling, and erection of the precast concrete units. In addition, the drawings provide the Architect-Engineer with a means of checking interfacing with adjacent materials. Good production drawings reduce plant costs and speed production by providing effective communications between the engineering-drafting and the production-erection departments of a precast plant. Additionally, the erection drawings provide the precaster with his only practical means of communicating with the General Contractor and Architect-Engineer.

The manufacturer should prepare and submit his drawings for approval in general accordance with the *PCI Architectural Precast Concrete Drafting Handbook* and the project specifications.

2.6.1—General

Samples of architectural precast concrete are intended to give information on the type of materials used, the quality of the concrete, and the type of finish. They are to be related to a specific project and should only be considered in this manner.

Prebid samples, as for all samples for architectural concrete, shall only be regarded as a standard for performance within the variations of workmanship and materials to be expected, even with good quality control. If the color or appearance of the cement or the aggregates is likely to vary significantly, samples showing the expected range of variations shall be supplied. The concrete placement and consolidation method used for samples shall be representative of the actual procedures used in the production of the element.

2.6.2—Shape and Size

It is recommended that there be a shape relationship between samples and the actual casting. Flat samples are not to be used for other than flat castings. For mullion units a rectangular cross section is not necessarily representative of a trapezium or other irregular sections.

The size of a sample shall relate to the maximum size of aggregate to be used and allow for realistic placement of the concrete and accurate expression of detail. Samples should be at least 12 x 12 in. Larger samples are recommended.

2.6.3—Identification

All submitted samples shall be clearly identified by manufacturer's name, date produced, and identifying code number, and name of project for which it was submitted. A permanent file of sample code numbers with all related data shall be maintained by the precaster to ensure future duplication of any sample submitted.

Information shall be provided with the submission of samples regarding the type of materials, quality of concrete and type of finish proposed. This information should be submitted both for facing mixes and backup mixes, if different. If both faces of the panel are to be exposed to view, samples of the workmanship, color and texture of the backing of the precast panels should be shown as well as the facing. Since the precaster must work with these criteria throughout production, he should be allowed to establish a latitude for some of the data as long as this range is reasonable.

The following information shall relate to the prebid samples and be made available to the Architect-Engineer upon request—these data may be used as standards for inspection during production:

- (1) *Concrete Mix.*
    - (a) Uniformly graded, or gap-graded.
    - (b) Cement content in pounds per cubic yard of concrete.
    - (c) Water-cement ratio.
    - (d) 28-day compressive strength.
    - (e) Unit weight.
    - (f) Slump range.
    - (g) Admixtures (types, source and amount).
    - (h) Water absorption at 28 days.
- (2) *Aggregates.*
    - (a) Type of material.
    - (b) Inertness.
    - (c) Hardness or abrasiveness.
    - (d) Maximum size.
    - (e) Cleanliness, e.g., silt and organic impurities.
    - (f) Soundness.
    - (g) Gradation, all standard sieves. Where percentages passing No. 50 and 100 sieves are high, anticipated fluctuations in these percentages should be supplied.
- (3) *Exposed Faces (exterior or interior).*
    - (a) Type of finish.
    - (b) Data on weather sealing, if applicable.

DIVISION III—PLANT FACILITIES

Section 1—General Objectives and Safety

3.1.1—General

Plant facilities represent the tools of the industry and as such must be maintained to the same standard of quality as set for the product.

Plants shall have general good housekeeping needed to efficiently achieve a high quality end product and to promote safe working conditions.

Architectural precast concrete plants should adequately provide for the following:

(1) Area to receive and store raw materials.
(2) Area for specialized batch plant.
(3) An enclosed or covered area (depending on the climate) for the casting operation.
(4) Area or building to house or protect products during finishing and curing.
(5) Area for fabricating of reinforcing steel, assembly of inserts, and other items cast in the concrete.
(6) Area for mold fabrication and storage.
(7) Area for laboratory testing and sample preparation.
(8) Area for storage of finished products.
(9) Proper roads and lanes to provide effective access to products, safe traffic flow, and handling of products without damage to them or the equipment.
(10) Efficient and adequate provision for surface drainage; in addition to rainfall, water accumulation from finishing must be removed.
(11) Cranes, hoists and other handling equipment adequate for the largest anticipated units without exceeding rated capacities.

3.1.2—Safety

A carefully planned program of good safety practices shall be developed for each precast plant. Each precasting plant, and each employee in the plant shall be required to comply with the *PCI Safety and Loss Prevention Manual.*

A person shall be made responsible for the plant safety program. He shall keep minutes of the Safety Committee meetings and record and review accidents. This person shall be thoroughly familiar with all operations of the plant. He shall also be familiar with the safety regulations of the authority having jurisdiction.

Housekeeping is the main consideration for a good, working lighting, bad tool locations, and poorly protected equipment will increase safety.

It shall be the responsibility of supervisory personnel to insure safety is never subordinated to production expediency. Any employee who will not abide by prescribed safety rules shall not be permitted to work in the precasting plant.

3.1.3—Special Safety Requirements

This Manual outlines safety measures for certain operations which may be included in some, but not all, plants, such as acid washing (see Article 5.6.8) and sandblasting of surfaces (see Article 5.6.5).

When architectural concrete elements are prestressed, the appropriate safety measures are covered in PCI MNL-116, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products.*

3.1.4—General Safety Requirements

The details of a safety program are not specified in this Manual, but are left to the individual plants to be tailored to their facilities, products and operations. As a guide, however, the following safety requirements, where applicable, should be covered:

(1) All electrical wire and equipment in use shall be of a type approved by the Underwriters Laboratories, Inc. Installation and maintenance shall comply with pertinent provisions of the National Electrical Safety Code. All electrical circuits and equipment shall be properly grounded in compliance with the Code. This means a three-wire polarized system on all tools, extension cords, receptacles, etc.

(2) All personnel shall be required to wear safety hats.

(3) All personnel shall be required to wear safety footwear.

(4) All personnel, when grinding, chipping concrete, finishing by sandblasting, acid washing panels or any other operation which is apt to damage the eyes, shall be required to wear safety glasses.

(5) All debris shall be removed from the vicinity of the work area not later than the end of each shift.

(6) The proper type and amount of fire-fighting equipment shall be installed in the areas where needed, particularly burning and welding areas, and workmen shall be trained in the proper usage.

(7) Hazardous and flammable materials shall be stored in separate areas or enclosures out of the immediate work area in accordance with the requirements of the authority

having jurisdiction. Materials such as acids shall be stored well protected from any production activities and such storage shall be clearly screened or marked.

(8) Hand tools shall be kept in good condition—sharp, free of broken handles, free of mushroomed heads, etc.

(9) Wire rope, slings, shackles, and other rigging equipment shall be kept in good condition. Personnel shall not be permitted beneath hung loads.

(10) Saws and other equipment shall be properly guarded.

(11) Welding areas shall be arranged and ventilated to protect workmen from welding flashes and excessive welding fumes. Welding and/or flame cutting shall not be allowed in the vicinity of sawdust or wood shaving accumulations.

3.1.5—Reporting Accidents

Supervisory personnel shall require all levels of labor to report immediately all job-connected accidents and injuries. Failure to so report may result in a loss of protection for both employer and employee. OSHA Report Forms 100 and 102 must be current at all times. A regular review of accident statistics for the plant shall be made.

Section 2—Batching and Mixing Facilities

3.2.1—General Requirements for Batching and Mixing Plants

Concrete batching plants may be simple manual equipment in which the operator sets batch weights and discharges materials manually, semi-automatic plants in which batch weights are set manually and materials are discharged automatically, or fully automatic electronically controlled plants in which mixes are controlled by means of selectors or punch cards. All of these plants are capable of producing concrete of the quality required for architectural precast concrete members provided they are adequately equipped and properly operated. Batching and mixing facilities shall have provisions for mixing concrete at hot and cold ambient temperatures.

Mixing and transporting of concrete may be performed by any of the following methods:

(1) Mixed completely in a stationary mixer and the mixed concrete transported to the point of delivery in a truck agitator or truck mixer. For concrete to be used in the immediate vicinity of the batching plant, concrete may be transported by conveyor, buckets or non-agitating trucks.

(2) Mixed partly in a stationary mixer and the mixing completed in a truck mixer.

(3) Mixed completely in a truck mixer (for backup mixes only).

Fine and coarse aggregate, as well as any special facing aggregate, shall be handled and stored by methods that will, insofar as practical, insure uniformity in grading and moisture content upon arrival at batch weighing equipment. Undersize material smaller than four-fifths of the minimum size for each size fraction of the course aggregate shall be restricted to 3 percent. Horizontally operating, vibrating screens, mounted over the storage bins, should be used when such uniformity cannot be attained by the methods normally used for storage and handling of coarse aggregate. Aggregation segregation occurs in each handling operation; therefore, rehandling of aggregates should be minimized.

When aggregates are to be stockpiled, the use of aggregate bins is preferred; but failing these, it is imperative that a hard, clean and well-drained base shall be provided for all aggregate stockpiles. If contamination cannot otherwise be avoided the area shall be planked or paved. Stockpiles shall be built up in horizontal or gently sloping layers. Trucks, bulldozers, or other vehicular or track equipment should not be operated on the stockpiles because in addition to breaking the aggregate, dirt is frequently tracked onto the piles. Intermixing of different materials shall be prevented by suitable walls or ample distance between piles. The wind shall be prevented from separating dry, fine aggregate, and stockpiles shall not be contaminated by swinging aggregate filled buckets or clams over the various stockpiled aggregate sizes.

When bagged aggregates are used, the individual sizes should be stored on pallets in a well drained, reasonably dry area. If stored outside, the bags should be protected with a polyethylene cover to prevent contamination from dust or deterioration of the bags from excess moisture in wet regions. Bagged aggregate shall be weighed prior to usage. Long periods of storage may require rebagging or other means to prevent breaking of bags when handled. Storage should be such that there is no mixing of sizes if some bags break and the aggregate is recovered.

When bins are used for storing aggregates, separate compartments shall be provided for fine aggregates and for each required size of coarse aggregate. Aggregate bins shall be filled by material falling vertically, directly over the outlet. They shall be kept as full as practicable at all times to avoid breakage and to minimize segregation. Depending on storage bin capacity and climate, aggregate storage may have to be suitably heated.

Storage bins (aggregate or cement) shall have the smallest practicable equal horizontal dimensions; round bins are preferable. Bottoms of circular bins should slope at an angle not less than 50 deg. from the horizontal toward a center outlet, while the bottom slope of rectangular bins shall slope at an angle not less than 55 to 60 deg., to avoid accumulation of fines in dead storage areas.

Procedures for handling and storage of aggregates are prescribed in further detail in the following publications of the American Concrete Institute, which are made a part of this section by reference:

(1) *Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete* (ACI 304–73).

(2) *Recommended Practice for Selecting Proportions for Structural Lightweight Concrete* (ACI 211.2–69).

3.2.3—Storage of Cement

Bulk cement shall be stored in weathertight bins or silos which exclude moisture and contaminants. Each type of cement shall be stored in a separate bin; it may be necessary to store each brand of cement used for facing concrete in a separate bin to ensure color uniformity of the concrete. Each compartment shall be designed to discharge freely and independently into the weighing hopper.

Cement silos not of circular construction shall be equipped with non-clogging air diffuser flow pads through which small quantities of low pressure air (3 to 5 psi) may be introduced intermittently to loosen cement which has settled tightly in the silos. Care should be taken to use minimum amounts of air since, in some dry climate areas, use of air may impart abnormal set characteristics to the cement. Storage silos shall be drawn down frequently, preferably once per month, to prevent cement caking.

Cement stored in bags shall be stacked on pallets or similar platforms to permit proper circulation of air and shall be stored clear of wall areas where condensation may occur. To avoid "pack set," cement shall not be stacked in piles higher than 14 bags, for a storage period of less than 60 days, and for longer periods, no higher than 7 bags.

Cement of different types shall be stored separately. Records should be kept of how long the cement has been in storage so the oldest stock can be used first. Any cement that develops lumps which cannot be reduced by light finger pressure shall not be used. Cement stored for over 90 days in the precast concrete manufacturer's plant shall not be used without further testing for conformity with ASTM C 150.

3.2.4—Measuring Equipment

Operation of batching equipment shall be such that the concrete ingredients are consistently measured within the following tolerances.

For *Individual Batchers*, the following tolerances shall apply

±1 percent of the required weight of material being weighed, or ±0.3 percent of scale capacity, whichever is greater.

Aggregates:

±2 percent of the required weight of material being weighed, or ±0.3 percent of scale capacity, whichever is greater.

Water:

±1 percent of the required weight of material being weighed, ±0.3 percent of scale capacity, or ±10 lbs., whichever is greater.

Admixtures:

±3 percent of the required weight of material being weighed, or ±0.3 percent of scale capacity, or ± the minimum dosage rate for one bag of cement, whichever is greater.

For *Cumulative Batchers* the following tolerances shall apply to the required cumulative scale reading:

Cement and other Cementitious Materials or Aggregates:

±1 percent of the required cumulative weight of material being weighed, or ±0.3 percent of scale capacity, whichever is greater.

Admixtures:

±3 percent of the required cumulative weight of material being weighed, or ±0.3 percent of scale capacity, or ± the minimum dosage rate per bag of cement, whichever is greater.

For *Volumetric Batching Equipment* the following tolerances shall apply to the required volume of material being batched:

Water:

±1 percent of the required volume of material being batched, or ±1 gallon, whichever is greater. (The mechanisms in most meters cannot respond to quantities less than 1-gallon increments.)

Admixtures:

±3 percent of the required volume of material being batched but not less than ±1 ounce, or ± the minimum recommended dosage rate per bag of cement, whichever is greater. (Where it cannot be determined what liquid admixture will normally be used in a volumetric dispenser, assume that the dosage will be at a rate of at least 1 fl. oz. per bag; admixtures with lower rates can be reconstituted to the point where the rate is 1 fl. oz. per bag or more.)

For ingredients batched by weight, the accuracy tolerances required of the batching equipment shall be applicable for batch quantities between 10 and 100 percent of scale capacity.

For water or admixtures batched by volume, the required accuracy tolerances shall be applicable for all batch sizes from minimum to maximum, as is determined by the associated cement or aggregate batcher rating.

Scales for measuring aggregates and cement shall be either of the beam, springless dial, digital, or load cell types. Gates charging automatic batches shall be arranged to operate with a suitable "dribble" to add small increments after closely approaching the required quantity.

For all types of batching systems, manual through automatic, the batchman must be able to read the load indicating devices from his normal station. However, where the controls are remotely located with respect to the batching equipment, monitors or scale-follower devices may be used if they repeat the indication on the master scale within ±0.2 percent of scale capacity.

All scales shall be maintained so they are capable of accuracy within 1 percent under operating conditions or within ±0.20 percent of scale capacity throughout the range of use. For direct digital read-out, the tolerance shall be increased to ±0.25 percent, to allow for the fact that digital readings are limited to whole-number values which cannot reproduce weight indications closer than ±0.05 percent of capacity. All exposed fulcrums, clevises and similar working parts shall be kept clean. Beam type scales shall be checked to zero load with each batch discharge.

For calibration of scales, standard test weights aggregating at least 500 lbs. shall be used. Calibration of scales shall be performed at intervals not greater than 6 months, or at any time there is reason to question their accuracy. Records shall be maintained of all calibrations.

Batchers for weighing cement, aggregates, and also water or admixtures (if measured by weight) shall consist of suitable containers freely suspended from a scale, equipped with necessary charging and discharging mechanisms. Batchers shall be capable of receiving rated load without contact of the weighed material with the charging mechanism. Provision shall be made for removal of overload. (For example, adequate clearance in the case of aggregate batchers; discharge ports in the case of cement batchers.) The batchers should be equipped with vibrators to aid in the smooth and complete discharge of the batch. Vibrators or other appurtenances shall be installed in such a way as not to affect accuracy of weighing, and wind protection shall be sufficient to prevent interference with weighing accuracy.

Cement batchers shall be provided with a dust seal between charging mechanism and hopper, installed in such a way as not to affect weighing accuracy. The weigh hopper shall be vented to per-means to insure complete discharge.

Fine and coarse aggregates may be weighed on separate scales or on a single scale which will first weigh one aggregate, then the cumulative total of agregates.

Separate scales shall be provided for weighing cement and other cementitious materials. Standard 94-lb. bags may be used without weighing, but any fractional bags shall be weighed. The use of automatic scales and cutoffs for cement is strongly recommended. Gates, valves, controlled screw feeders, air slides or other effective devices that will permit a precise cutoff shall be used to charge the cement weighing equipment.

The water measuring device shall be arranged so the measurements will not be affected by variable pressures in the water supply line. Measuring tanks for water shall be equipped with outside taps and valves to provide for checking their calibration not less frequently than every 90 days. Volumetric tank water batchers shall be equipped with a valve to remove overloads.

Where concrete is placed regularly during sub-freezing weather, minimum heating capacity for water and/or aggregates of 15 boiler horsepower per 100 cu. yds. average daily cold weather production is required.

A separate dispenser shall be used for each liquid admixture in regular use, except that more than one admixture can be batched through a single dispenser if the admixtures are compatible or if the dispenser is flushed with water after each cycle.

All dispensers shall provide for diversion of the measured dosage for verification of the batch quantity and batching accuracy shall be checked at least every 90 days. Bulk storage tanks, drums, and calibrated sight tubes should be vented so that they do not become air bound and restrict flow.

Volumetric admixture dispensers shall be provided with visual indication or interlock cutoff when liquid admixture supply is depleted.

3.2.5—Mixers

Mixing equipment shall be of capacity and type to produce concrete of uniform consistency, with cement and water content and aggregate distribution uniform from beginning to end of each batch as discharged.

Low-slump mixers of the vertical or horizontal shaft type are recommended although truck mixers may be used for backup mixes. For a description of the various mixer types, refer to the *Concrete Plant Mixer Standards,* Mixer Manufacturers Division of the Concrete Plant Manufacturers Bureau. Mixers with a rated capacity of 1 cu. yd. or larger shall conform to the requirements of these Standards.

Agitators may be truck mixers or truck agitators. Each mixer and agitator shall have attached thereto, in a prominent place, a durable plate or plates marked with the various uses for which the equipment is designed, the capacity of the drum or container in terms of the volume of mixed concrete, and the speed of rotation of the mixing drum, blades, or paddles. The batch size shall not exceed the manufacturer's recommended capacity of the mixer. Low-slump concrete may require smaller loads.

Stationary mixers should be equipped with a timing device that will not permit the batch to be discharged until the predetermined mixing time has elapsed and will ensure that the safe maximum mixing time will not be exceeded. Alternatively, the timing device may cause the mixer to discharge into a holding hopper. In addition, further entry of materials into the mixer may be prevented when the weight or volume of the content of the holder hopper has reached a certain level. Truck mixers shall be equipped with a counter by which the revolutions of the drum, blades or paddles may be verified.

Agitators shall be capable of maintaining the concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity. All types of mixers and agitators shall be capable of ready discharge of concrete at the specified slump.

All mechanical details of mixers or agitators, such as water measuring and discharge apparatus, condition of blades, speed and rotation of the drum or blades, general mechanical condition of the unit and cleanliness shall be checked frequently. Mixers shall be examined daily for changes in condition due to accumulation of hardened concrete or mortar, or to wear of blades. Any accumulation of hardened concrete shall be removed. The blades shall be replaced or repaired, in accordance with manufacturer's design and arrangement for that particular unit, when (1) any part or section is worn as much as 10 percent below the original height of the manufacturer's design, or (2) if the gap between the pan (or drum) and blades exceeds one-quarter of the maximum size of the coarse aggregate or ¼ in. whichever is smaller. A copy of the manufacturer's design, showing dimensions and arrangement of blades, shall be available at the plant at all times.

Section 3—Production and Curing Facilities

3.3.1—Area Requirements

The production and curing areas must be designed for controlled production of quality architectural precast concrete units and be of the products manufactured for a well-organized, continuous operation. The production area must be protected against rain, wind, dust, and direct sunlight and be equipped with heat facilities to provide proper curing and prevent the ambient temperature from dropping below 50 F. Adequate lighting of plants shall be provided for all operations not completed during daylight hours.

3.3.2—Mold Fabrication and Storage

Plastic mold fabrication facilities shall be located in clean shops of fire resistant construction capable of maintaining constant working temperatures above the minimum required for the specific raw materials. Mold shops using either wood or plastic shall have adequate dust collection and ventilating equipment.

All form fabrication shops shall have exits and fire-fighting equipment in relation to space, materials and overall hazards and to meet the requirements of the authority having jurisdiction. Fire-fighting equipment shall be maintained in working condition and placed in accessible and well-marked locations.

3.3.3—Reinforcing Fabrication and Storage

Reinforcing steel and hardware shall be kept free of contamination and stored separately or marked in a neat and orderly fashion so that different types, grades, and sizes can be identified and recognized through the entire production operation. Bundles or sheets of reinforcing materials shall be kept straight and free of kinks until cut and bent to final shape to facilitate dimensional control within established tolerances. All reinforcing steel should be stored on blocks, up off the ground. Special attention must be given to prevent loose rust from forming or the steel from becoming contaminated with grease or oil.

Adequate space and equipment must be provided for the construction of rigid reinforcing cages to precise dimensions when required. Where weather conditions may interfere with this operation, protection against rain or cold weather shall be provided. This same area should be used to store special plates, inserts and other items to be cast into the product.

Work benches or jigs where welding is performed shall be so arranged that workmen are protected from welding flashes and the area shall be ventilated to avoid excessive welding fumes.

3.3.4—Casting Area and Equipment

The casting area should provide flexibility in planning and spacing of the molds and efficient movement of workers, materials and equipment involved in placing, initial curing, and stripping of products. Molds should be arranged for good aisle space, storage of parts of the mold and clean-up of spillage of concrete such that good housekeeping is not difficult. Facilities shall be provided for post-tensioning or pretensioning, if required.

The concrete handling equipment shall be such that it will convey concrete from the mixer to the form:

(a) Without undue delay.
(b) Without segregation of aggregates and paste.
(c) In sufficient quantities to avoid undue delays in consolidation.
(d) With uniform consistency.
(e) With ease of discharge into forms.
(f) With equipment capable of being easily cleaned and maintained.
(g) With control of concrete temperatures.

The casting area must be supplied with equipment in good operating condition for consolidation of the concrete after placement in the mold. Concrete vibrators can be divided into two main classes—internal and external (see Appendix D). These vibrators may be used singly or in various combinations. This equipment is generally either electrical or air powered. Provisions must be made to supply the power required for these units with both safety and adequacy in mind.

In the case of electrical power, use three-wire polarized system with branch fuse circuits, broken down with plug-ins, or use power sources for each vibrator. There should be no drop in voltage or air pressure when one or all vibrators are in operation. The power supply should not have surges in either amperage or voltage. The vibrators should not be overloaded. As a rule, a motor overload cutout should be used with electric external vibrators.

Provisions should be made to use speed controls that maintain constant speed under load such as is the case of single phase induction motors used with or without frequency converters. When using electric vibrators, all power cables and connectors shall be maintained in good condition. Vibrators should not be lifted or carried by the electric cables.

Since internal vibrators are used in wet (conductive) locations, all electric units should be grounded to the power source. Generator sets supplying power should also be grounded, in order to maintain continuity of the grounding system. (Units operating at less than 50 volts, or which are protected by an approved double insulation system are excepted.) In the United States, electric vibrators are subject to *National Electric Code*, Article 250-45.

In the case of air vibrators, either internal or external, an ample reserve of clean, moisture-free air shall be supplied at the pressure required. Frequency depends on air pressure—if the air supply the storage supply, to decrease the pressure drop, and to increase the efficiency of the air compressor. The air pressure at the vibrator should be regularly checked, either by installing an ordinary dial gage in the line, or by inserting a needle gage in the air hose. Air hoses should be blown clean before connecting the vibrators. Also the air vibrator lubrication system should be checked to be certain it is filled with oil and that the air filter is in good condition.

There should always be at least one spare vibrator in the plant because a vibrator can often get out of order. Preventative maintenance recommended by the vibrator manufacturer should be strictly followed. When vibration is finished for the day, vibrators should be cleaned and concrete spills removed. It may be desirable to cover form vibrators to avoid concrete dropping on them.

Whether the consolidation equipment provides internal or external vibration, or a combination of both, its frequency and amplitude shall be designed, tested and proven for the volume, configuration and placing technique of the element and the proportioning and consistency of the concrete for that element.

3.3.5—Finishing and Curing Area

The finishing area must provide for varying types of finishes to be produced by the particular plant as mentioned in Division V, Section 6, with special attention to the following:

Retarded Finish (See Article 5.6.3)—Ventilation, removal of retarded cement paste, acid washing and rinse washing with proper disposal of these solids and solutions must be provided.

Sand or Abrasive Blast (See Article 5.6.5)—Large air compressor capacity, ample abrasive supply, excellent ventilation and very careful safety protection must be provided for the operator.

Acid Etched Finish (See Article 5.6.8)—When performing acid etch or acid wash of panels, ventilation, and protection to equipment and workers must be provided. Special safety and disposal methods must be observed.

Lighting is extremely important in the finishing area and at the point where final inspection is made before the panels reach the final storage. This is where they must be compared to the samples for color and texture. Wherever possible, the light should compare to daylight as closely as possible.

The curing area must provide protection and storage space until the panels meet the requirements of Article 5.5.5. Facilities should provide a well-drained area for steam curing or moist curing with adequate covering to prevent moisture loss. In the case where units will receive no further treatment prior to storage and delivery, they should be protected from contamination by other operations in the plant such as finishing by sandblasting. Panels that are to receive a sealer must be treated and cured during the period required by the coating manufacturer's recommendation.

Provision should be made to repair damaged products in either the finish or curing area of the plant or a special area for this purpose. Repairs should be avoided in the yard storage area or on the truck just prior to shipment.

3.3.6—Handling Equipment

The production facilities shall include adequate product handling equipment maintained in good working condition. Handling equipment shall be capable of safely moving, stacking, retrieving and loading elements without endangering personnel, damaging the products or exceeding rated capacities.

All in-house designed lifting equipment shall be clearly marked with its appropriate safe load capacity. If mobile equipment is to be used, the ground shall be stable and firm for it to operate properly.

Section 4—Storage of Finished Products

3.4.1—Area Requirement

The storage area shall be of adequate size to allow safe storage and easy access to the products by the handling equipment. The area shall be clean, well-drained and stabilized to minimize differential settlements under all weather conditions and to minimize soiling, warping, bowing, chipping or cracking of the elements. The storage area should be inspected after hard rains or large snow melts for washouts and other damage.

Adequate walkways and vehicle aisles shall be provided and designated. If men and vehicles are expected to use the same aisles they should be wide enough for the vehicles to be able to pass a man without endangering him. All walkways and vehicle aisles shall be kept clear of all debris, scrap metal, pieces of strand, wire rope ends, nails, welding rods and other tripping or puncture hazards.

Overhead wiring and other overhead obstructions in the storage area shall be prohibited. All lighting and power supply lines shall be installed underground.

Section 5—Laboratory Facilities

3.5.1—General

The manufacturer shall maintain or engage an adequately equipped laboratory in which investigation and development of trol testing.

The laboratory facilities shall be in a protected area with environmental controls to ensure good working conditions. The facilities shall include temperature and humidity controlled rooms or containers for the curing of test cylinders. Laboratory equipment shall be maintained in proper condition and verified as needed, but not less than annually, and records kept on file.

3.5.2—Laboratory Equipment

Minimum equipment in a laboratory for an architectural precast concrete plant includes the following:

(1) Scale with 50-kg. capacity.
(2) Scale with 2-kg. capacity and accuracy in 0.1 grams.
(3) Standard measuring bucket of ½ cu. ft.
(4) Heating element or hot plate.
(5) A series of standard sieves conforming to ASTM E 11 including 1 in.—¾ in.—⅝ in.—½ in.—⅜ in.—#4—#8—#16—#30—#50—#100—#200 and pan.
(6) Two flat pans for drying materials.
(7) Slump cone and rod and, if required, Vebe consistometer.
(8) Air meter—generally a pressure type is satisfactory; with lightweight concrete a volumetric type is required.
(9) Maximum-minimum thermometer.
(10) Concrete thermometer.
(11) Measuring tapes.
(12) Recording thermometers.
(13) Two sets of three 2-in. metal cube molds for mortar tests.
(14) Two sets of three 4-in. metal cube molds for concrete tests.
(15) 6 x 12-in. or 4 x 8-in. metal cylinder molds.
(16) Two measuring glasses (1000 ml. and 18 in. high).
(17) Miscellaneous chemical glassware.
(18) Trowels, scoops, pails, shovels, etc.
(19) Concrete impact hammer (Swiss hammer).
(20) R-meter or covermeter.
(21) Access to concrete testing machine with 400,000 lbs. capacity, conforming to ASTM requirements.
(22) Mechanical shaker.
(23) Aggregate splitter.
(24) Drying oven.
(25) Cylinder capping facilities.
(26) Fog room or water tank.
(27) Applicable ASTM, ACI, AWS and PCI reference literature.

3.5.3—Operating Instructions

Operating instructions shall be obtained for all testing equipment. These instructions shall be kept in the laboratory and shall be carefully followed by all testing personnel.

Testing machines shall be kept clean and no attempt shall be made to use them beyond their rated capacities. Machines must be capable of applying loads at the specified rate. They shall be equipped with a guard that will protect personnel from flying debris. Testing machines should be calibrated so the maximum error is not more than ±1 percent of full scale reading. Calibration shall be performed whenever there is reason to doubt the accuracy of indicated loads, or at least annually. Calibration curves shall be available at all times and used by testing personnel.

DIVISION IV—MATERIALS

Section 1—Concrete Materials

4.1.1—General

With architectural precast concrete, any change in materials or proportions will affect the surface appearance. The quality control inspector must continually observe and check for changes. A large change in aggregate color and gradation will affect the uniformity of the treated texture particularly where the aggregate is exposed. Changes in proportions or color of materials affect the uniformity of untreated surfaces. In smooth concrete the color of the cement (plus pigment) is dominant. If the concrete surface is progressively removed by sandblasting, retarders or other means, the color becomes increasingly dependent on the fine and coarse aggregates.

4.1.2—Cement

Unless otherwise specified, the precaster should have the choice of type and kind of cement to use to achieve concrete with the specified physical characteristics. Cements shall be selected to provide predictable strength and durability as well as proper color. Cement performance can be influenced by atmospheric conditions, and cement has an influence on finishing techniques, mix design requirements and casting procedures.

Types I or III, gray, white or buff, conforming to ASTM C 150, are generally used for architectural precast concrete. Types II, IV and V or cements conforming to ASTM C 595 may be used under certain conditions but should be restricted to properly designed, evaluated and proven mixes. There are also available colored cements conforming to ASTM C 150 which are produced by adding pigments to white cement during the production process. Air-entraining admixtures are recommended over interground air-entraining agents in cement to provide better control of air content.

To minimize the color variations of the facing mix, cement of the same type, brand and color from the same mill shall be used throughout a given project. White cement (from one source only) is generally subject to less color variations than gray cement. A mixture of white and gray cements may be used to improve color uniformity. Uniformity normally increases with increasing percentage of white, but the gray color is dominant. If such a mixture is desirable for reasons of uniformity, the Architect should state the required percentage of white cement in the contract documents.

the selection of concrete proportions was based.

4.1.3—Facing Aggregates

Fine aggregates for facing concrete, other than lightweight aggregates, shall consist of high quality natural sand, or sand manufactured from coarse aggregate. Fine aggregates shall comply with ASTM C 33, except for gradation which can deviate to achieve the texture mutually agreed to by the Architect and precast manufacturer. The gradation shall be consistent. Variations in fineness modulus shall not exceed ±0.20 from the average value utilized for the mix design.

The percentage of the fine aggregates passing the No. 100 sieve should be limited to a maximum of 5 percent, or variations in this percentage should be limited to 1 percent of the amount established in the mix design to ensure better uniformity of concrete mixes. Material finer than No. 200 sieve (ASTM C 117) shall be limited to 3 percent for fine aggregate and 1 percent for coarse aggregate. In the case of manufactured sand or crushed aggregates, if the material finer than the No. 200 sieve consists of the dust of fracture, essentially free from clay or shale, the limits may be increased to 5 percent for sand and 1.5 percent for coarse aggregates. Excessive quantities of minus No. 200 fines may act as an unwanted coloring agent, decrease strength, increase the mixing water requirements, and increase the rate of slump loss and drying shrinkage. These limitations may require double washing of aggregates, but the premium for this is justified by the increased uniformity of color.

Fine aggregate shall be obtained only from approved sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete-making properties of the aggregate have been demonstrated. Once the soundness and mortar-making properties of fine aggregate are established, further tests for these properties are generally not required so long as the source and type of aggregate remain unchanged.

Coarse aggregate for concrete, other than lightweight concrete, shall conform to the requirements of ASTM C 33, except for gradation. Coarse aggregates for facing concrete shall be of the size, shape, gradation and color required for architectural effect. A variety of aggregates are used to impart the desired color, tone and texture, including selected gravels; crushed stones, such as quartz, granite, marble and limestone; and the manufactured aggregates such as glass and ceramic materials. Any combination of these aggregates may be used for contrast provided desired levels of strength, durability and workability are met.

The nominal maximum size of the aggregate in the concrete mix shall not be larger than one-fifth of the narrowest dimension between sides of forms, one-third of the depth of slabs, nor three-quarters of the minimum clear spacing between individual reinforcing bars or bundles or bars or pretensioning tendons or post-tensioning ducts. These limitations may be waived if, in the judgment of the Architect-Engineer, workability and consolidation methods are such that the concrete can be placed without honeycomb or voids.

Flat pieces and elongated pieces (slivers) will produce irregular and non-uniform finishes when exposed and do not hold well in the concrete matrix. These particles should be limited to a maximum of 15 percent by weight. For returns, this percentage may have to be reduced in order to obtain a uniform texture.

Coarse aggregate shall be obtained only from approved sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete-making properties have been demonstrated. Aggregates to be exposed or other materials used to face architectural precast concrete shall be evaluated or proven in the anticipated service environment before their use on a project. When an aggregate source is specified that does not meet the requirements of this Manual, the precaster shall notify the Architect-Engineer in writing before start of production.

Once a sample panel has been approved by the Architect-Engineer, no other source of exposed aggregate or facing material shall be used for the project, unless certified to be absolutely equivalent in quality, gradation and color.

The precast concrete manufacturer shall verify that adequate supply from one source (pit or quarry) for each type of aggregate for the entire job will be readily available and, if possible, he should obtain the entire aggregate supply prior to starting the project, or have the aggregate supply held by the aggregate supplier.

Facings of any suitable material such as cut stone slabs, ceramic and glass products, oversized natural or crushed aggregates, aluminum or stainless steel sheets or sections may be used for precast concrete panels. Each of these special facing applications shall be properly designed, tested and proven before use both with respect to suitability of the material and to the effect of its interrelationship with the precast concrete. Where a service record is not available, or where the application has a major unique aspect, establish the relative durability of the proposed construction, should be obtained.

4.1.4—Backup Aggregates

Aggregates in backup concrete shall comply with ASTM C 33 or ASTM C 330 except for gradation. In general, the maximum size of coarse aggregate should not exceed three-quarters of the minimum clear depth of cover over reinforcing steel.

All backup aggregates shall be from approved sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete making properties have been satisfactorily demonstrated.

4.1.5—Aggregates for Lightweight Concrete

Lightweight aggregates shall conform to the requirements of ASTM C 330. It is particularly important that lightweight concrete mixes be subjected to a program of testing by production methods which will demonstrate the strength and weight of the concrete produced.

Moisture absorptive characteristics of the aggregate should be known within close limits. Methods for storage and handling should deliver the aggregate to the mixer in a condition as near as practical to saturated surface dry or with a constant moisture content. The ACI Committee 213 report, *Guide for Structural Lightweight Aggregate Concrete,* provides a thorough discussion of lightweight aggregate properties including proportioning and mixing practices.

Provisions for testing shall be as stipulated in Articles 2.1.2 and 2.1.3 except tests for gradation, weight, and impurities shall be made in accordance with requirments of ASTM C 330.

For load-bearing concrete, the modulus of elasticity of the concrete mix, depending on the actual lightweight material used, shall be established in accordance with ASTM C 469 before any lightweight material is used. This figure shall be available for concrete with only coarse lightweight aggregates and for concrete with all aggregates being lightweight.

Although lightweight concrete is used primarily as a backup concrete, there are instances of its acceptable use in exposed aggregate applications. Before a specific lightweight aggregate is so applied, its behavior and performance should be thoroughly evaluated. Lightweight aggregates employed in exposed face mixes shall conform to ASTM C 330, with the further provision that their absorption, as defined in ASTM C 330, shall not exceed 11 percent. They also should be tested for iron staining characteristics. It is recommended that they not be used in cold or humid climates (if exposed to the weather) unless their performance has been verified by tests or records of previous satisfactory usage in similar environments.

4.1.6.—Mixing Water

Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalies, salts, organic materials, or other substances that may be deleterious to concrete or steel. Particular care must be taken to be certain that the water does not contain iron, iron oxides, or rust, which will cause staining in light or white concretes. In addition, the mixing water for prestressed concrete, or for concrete containing aluminum embedments or galvanized reinforcement and/or hardware, including that portion of the mixing water contributed in the form of free moisture on the aggregates, shall not contain deleterious amounts of chloride ions.

4.1.7—Admixtures

When an admixture is being evaluated for a given job the materials to be used in that job should be used in a trial mixture program. The trial mixture program should be designed to determine the effect of the admixture on the properties of the concrete under the conditions of use, particularly with respect to temperature and humidity. The admixture shall be shown capable of maintaining essentially the same composition and performance throughout the work as the product used in establishing concrete proportions. Admixtures sometimes are used for a specific effect, such as air entrainment, a reduction in water content, or retardation of set. Admixtures should be carefully checked for compatibility with the cement or other admixtures used. Manufacturer's recommendations in their use and optimum quantities should be observed subject to field checking and experience.

When using white or light colored cements, special tests may be needed to determine any effect of the admixture on the final color. Several admixtures, particularly those containing lignosulfonate, can cause discoloration of the surface, and a check should be made by trial mixtures to determine that the admixture will not discolor the concrete. The same admixture should be used throughout any part of a project where color uniformity is required.

A specific level of air content shall be maintained in concrete elements exposed to freeze-thaw, deicers and wet-dry conditions. Air entrainment shall be obtained by the use of admixtures conforming to ASTM C 260.

Water-reducing admixtures conforming to ASTM C 494 may be the workability of the concrete without adding water. Water-reducing admixtures may also be helpful with harsh facing mixes which necessarily have poor aggregate gradation.

Set-retarding admixtures conforming to ASTM C 494 may be used during hot weather concreting or, in some cases, to achieve good bond between facing and backup concrete. Set-acceleration admixtures containing calcium chloride, or other admixtures containing calcium chloride, shall not be used. Admixtures containing chloride ions shall not be used in prestressed concrete, or in concrete containing aluminum embedments or galvanized reinforcement and/or hardware, if their use will produce a deleterious concentration of chloride ions in the mixing water and cause corrosion.

Where a particularly smooth surface is desired, the addition of fine minerals or pozzolans conforming to ASTM C 618 may be desirable. These materials also may be added for additional workability or to reduce the possibility of efflorescence provided no detrimental change is experienced in the desired architectural appearance.

The preparation of any admixture prior to its introduction into the concrete mixture should follow the recommendations of the manufacturer as well as established and accepted procedures. Admixtures shall be stored in such a manner as to avoid contamination, evaporation, or damage. For those used in the form of suspensions or non-stable solutions, agitating equipment shall be provided to assure thorough distribution of the ingredients. Liquid admixtures shall be protected from freezing and from temperature changes which would adversely affect their characteristics.

Detailed recommendations for storage and handling of admixtures are given in the ACI Committee 212 report, *Guide for Use of Admixtures in Concrete.*

Any coloring pigment used integrally in the facing mix, or as a surface colorant, shall be a finely ground natural or synthetic mineral oxide or an organic phthalocyanine dye with a history of satisfactory color stability in concrete. The amount and type of coloring agent used shall not reduce the quality of the concrete below that specified. Amounts in excess of 5 percent by weight of cement seldom accomplish further color intensity; amounts greater than this shall not be used.

ASTM is currently developing specifications for pigments for coloring concrete. In the interim, a coloring pigment should fulfill the following requirements:

(1) It must produce intense chroma, brilliancy, strength or intensity.

(2) It must be durable under exposure to sunlight and weather, and resist change in the presence of alkalies and weak acid.

(3) It must be of a composition that will not react chemically with cement to the detriment of color, setting time, or strength of the concrete.

(4) The pigment must be at least 97 percent insoluble in water.

(5) A minimum of 95 percent of the pigment must pass the No. 325 sieve.

(6) The pigment should be manufactured or processed to a standard and should be checked for uniformity from shipment to shipment.

Section 2—Reinforcement and Hardware

4.2.1—Reinforcing Steel

Steel reinforcing bars shall be of the designated sizes and grades and shall conform to the following applicable specifications as shown on the production drawings:

Billet-Steel Deformed Bars	ASTM A 615
Rail-Steel Deformed Bars	ASTM A 616
Axle-Steel Deformed Bars	ASTM A 617
Low Alloy Steel Deformed Bars	ASTM A 706
Bar or Rod Mats	ASTM A 184

If bars other than the types listed above are to be used, their required properties shall be shown on the production drawings. In addition to the ASTM specification requirements, all reinforcing bars shall meet the requirements of ACI 318.

Steel wire reinforcement, other than prestressing tendons shall conform to the following applicable specifications:

Wire	ASTM A 82
Deformed Wire	ASTM A 496
Welded Wire Fabric	ASTM A 185
Welded Deformed Wire Fabric	ASTM A 497

The as-drawn or galvanized welded wire fabric may be smooth or deformed with the mesh spacings and wire gages as shown on the production drawings. Galvanized welded wire fabric when required should be smooth. In addition to the ASTM specification requirements, all wire reinforcement shall meet the requirements of ACI 318. It is recommended that welded wire fabric, used as part of reinforcing cages, be purchased in large sheets rather than rolls for better control of straightness.

All reinforcing materials shall be purchased and maintained without excessive rusting to comply with normal specification rewhere they might mar concrete surfaces.

Hot dip galvanizing of reinforcing steel shall conform to ASTM A 123.

4.2.2—Prestressing Steel

Materials in common usage for prestressing tendons consist of:

(1) *Pretensioning*
  (a) Uncoated, stress-relieved strand conforming to ASTM A 416, Grades 250 and 270.
(2) *Post-Tensioning*
  (a) Strand as described above either singly or in multiple parallel strand units with wedge type or other adequate anchorages.
  (b) Uncoated, stress-relieved wire conforming to ASTM A 421 in multiple parallel units with wedge-type, button head or other adequate anchorages.
  (c) High strength, stress-relieved bars conforming to ASTM A 722 with wedge type, threaded or other adequate anchorages.
  (d) High strength, stress-relieved large cables with socketed or extruded ends fitted with anchorage nuts on the peripheries of the sockets.
  (e) Coated strands.

Certain fundamental requirements apply to all materials for prestressing tendons, including:

(1) High ultimate tensile strength, approximately 145,000 and 160,000 psi for bars, 250,000 and 270,000 psi for strand, and 240,000 and 250,000 psi for wire.
(2) Ductility as measured by an elongation of 3½ percent minimum in a gage length of 24 in., unless otherwise specified in ASTM or other applicable specifications.
(3) Either mechanical or thermal stress relief of internal stresses induced by the processes of manufacturing high strength steels.

See the appropriate sections of PCI MNL-116, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products,* for additional information.
prepared by the designers, but also for brittleness or breakage.

4.2.3—Connections and Inserts

All hardware—connection items, inserts or other appurtenances—shall be clearly detailed on the erection drawings for Architect-Engineer approval.

Miscellaneous metal components, such as plates, bolts, anchors, and the like, should be fabricated, based on clear and well-defined specifications, taking into account grade of steel, radius of bends, size of welds, type of welding rods, and sequence of welding of the various components. After fabrication, they must be checked, not only for conformance with the specifications and drawings If these components are to be galvanized, the same verification process also must be done after galvanizing.

Hardware should be made from materials that are ductile. Plates and angles shall be mild steel and steel for anchors shall be of a grade and strength similar to the hardware material which it anchors to minimize welding complications. (Mild steel flats and bars or reinforcing bars with low carbon content are recommended.) Brittle materials, such as low shock resistant, high carbon steels or gray iron castings, shall not be used. Malleable cast iron may be satisfactory. Wooden inserts shall only be used if properly impregnated to avoid the tendency to swell and crack the concrete. Short pieces evenly spaced shall be used rather than one continuous piece and they shall have bevelled sides (reverse draft). The most suitable wood is Southern pine or Douglas fir with a high resinous content.

The following are applicable ASTM specifications for hardware and inserts:

(1) Carbon steel bars—ASTM A 675, Grade 65 (for completely encased anchors).

(2) Structural steel—ASTM A 36 (for carbon steel clip anchors).

(3) Stainless steel—ASTM A 666, Type 304, Grades A or B. (Stainless steel anchors for use when resistance to staining merits extra cost.)

(4) Carbon steel plate—ASTM A 283, Grades A, B, C or D.

(5) Malleable iron castings—ASTM A 47, Grades 32510 or 35018.

(6) Carbon steel castings—ASTM A 27, Grade 60-30 (for cast steel casting clamps).

(7) Anchor bolts—ASTM A 307 or A 325 (for steel bolts, nuts and washers).

The finish for the hardware and inserts when required may consist of an oil base shop primer, hot dip galvanizing (ASTM A 153), or a cadmium coating (ASTM A 165). Threaded parts should not be hot dip galvanized.

Channel type (continuously slotted) inserts in precast connections shall not be used unless carefully studied and evaluated. Aluminum conduit or inserts shall not be embedded in structural concrete unless effectively coated with bituminous paint, alkali-resistant lacquer such as methacrylate or zinc chromate paint, or tion between aluminum and steel.

The materials of a connection shall be selected and joined in a manner such that embrittlement of any part of the assembled connection will not occur. If more than one material is used in a connection, abutting materials shall be selected such that corrosion is not induced.

Proper emphasis shall be placed on hardware requirements, such as appearance, location, and protection against corrosion, for architectural concrete elements exposed to the weather, either during storage or in their installed location. Care must be taken to prevent chemicals, such as muriatic acid, from contacting the hardware and causing corrosion.

For all hardware some protection, such as rust-inhibiting paint, is recommended for metal surfaces exposed to the weather during storage. Where the concrete surface will be exposed to the weather in the finished structure or subject to corrosive conditions including condensation, the portions of all accessories within ½ in. of the concrete surface shall be made of non-corrosive materials such as stainless steel or protected against corrosion by hot dip galvanizing, cadmium plating, zinc metallizing or coating with a zinc-rich paint.

Connection hardware shall be galvanized, if required, following fabrication. Where galvanizing is used as a protective coating for cold worked reinforcing steel or for wrought steel products which have been cold formed, such as by bending or punching, parts should be blast cleaned and flash pickled. Malleable castings should be heat treated, prior to galvanizing, by heating to 1250 F and water quenching.

4.2.4.—Handling and Lifting Devices

All inserts or lifting devices, required to efficiently facilitate the handling and erection of units, shall be located, detailed and identified on the erection drawings for typical units in order to check for interference with other functions, interior finishes, insulation and mechanical services. Details of lifting devices should include the notation of possible corrosion protection where such hardware is left in the units. If the handling devices interfere with any other function, erection drawings should include removal instructions as well as possible field repairs. Protruding lifting devices (strand or wire) are normally removed after panel installation by burning.

Lifting devices are normally strand, cable or nylon rope loops projecting from the concrete, or threaded inserts. Brittle materials such as cold bent reinforcing bars shall not be used.

All lifting devices used externally, or installed in the element, shall be capable of supporting the element in all attitudes anticipated during the course of manufacture, storage, delivery and erection. Safe loads for lifting inserts should be established by full-scale tests to failure performed by a licensed professional engineer. For all lifting inserts a safety factor of at least four (which includes 100 percent impact) should be used to determine safe working loads.

Connection hardware should not be used for lifting or handling, unless carefully reviewed and approved by enginering personnel.

Section 3—Insulation

4.3.1—Materials

Insulating materials normally used in sandwich panel construction include foamed plastic (polystyrene and polyurethane), glasses (foamed glass and fiberglass), foamed or cellular lightweight concretes, and lightweight mineral aggregate concretes. The use of self-extinguishing types of insulation is recommended.

Properties of insulating materials which enter into design considerations are thermal and vapor transmission characteristics, volume stability, bond strength and, to a lesser degree, compressive strength and modulus of elasticity. All relevant information on these properties shall be on file at the plant.

Insulation materials shall be stored under cover and protected from damage in storage and during concrete placement.

Section 4—Welding Electrodes

4.4.1—Materials

All welding electrodes shall be of a type suitable for the chemistry of the steel being welded (see Table 2).

All low hydrogen electrodes conforming to AWS A5.1 shall be purchased in hermetically-sealed containers or shall be dried for at least 1 hr. at a temperature between 500 F and 650 F before they are used.

All low hydrogen electrodes conforming to AWS A5.5 shall be purchased in hermetically-sealed containers or shall be dried at least 2 hrs. at temperatures between 700 F and 800 F before being used.

Electrodes shall be dried as specified above prior to use if the hermetically-sealed containers are damaged, improperly stored, or for any reason the electrodes are exposed to high moisture conditions. Immediately after removal from hermetically-sealed containers or from drying ovens, electrodes shall be stored in holding ovens held at a temperature of 50 F to 250 F above ambient temperature. E70 series electrodes that are not used within 4 hrs., E80 series within 2 hrs., E90 series electrodes within 1 hr., or

Base Metal	Electrode Classifications for Welding Processes	
	Shielded Metal-Arc Low Hydrogen Electrodes	Flux-Cored Arc
ASTM A 615 Grade 40 ASTM A 617 Grade 40	AWS A5.1 or A5.5 E70XX*	AWS A5.20 E70T-X (Except −2 & −3)
ASTM A 616 Grade 50	AWS A5.5 E80XX	Grade E80T
ASTM A 615 Grade 60 ASTM A 616 Grade 60 ASTM A 617 Grade 60 ASTM A 706	AWS A5.5 E90XX	Grade E90T
ASTM A 615 Grade 75	AWS A5.5 E100XX	Grade E100T

*XX = 15 or 16.

E100 series within ½ hr., after removal from hermetically-sealed containers or from a drying or storage oven, shall be redried in a drying oven before use. Electrodes which have been wet shall not be used.

DIVISION V—PRODUCTION

Section 1—Project Samples

5.1.1—General

Immediately after award of the contract, the precast concrete manufacturer shall prepare and submit for approval, before casting any units, a representative sample or samples of the required color and texture, providing his prebid samples were not the basis for the specifications or providing the prebid approval method of Article 2.6.3 was not used. When approved, the samples shall form the basis of judgment for the purpose of accepting the appearance of architectural finishes. These samples also shall establish the range of acceptability with respect to color and texture variations, surface defects and overall appearance.

When submitting these samples the conditions outlined in Division II, Section 6, should govern.

All project samples shall be submitted promptly for early acceptance to provide sufficient lead time for procurements and production of units for the project.

Sample approval shall be in writing with reference to the correct sample code number or written on the sample itself. Approval of the sample by the Architect-Engineer should indicate authorization to proceed with manufacturing, unless such authorization is expressly withheld.

5.1.2.—Mockups and Initial Production Approval

Frequently, the expenditure for mockups, either of a full scale portion of a panel or the entire typical unit, will be authorized. The larger samples should contain typical cast-in inserts, if requested. These production samples are not to be confused with the prebid samples on which the Architect-Engineer based his initial selection of aggregates, color and texture. It should be clearly stated in the contract documents how long the production units or the mockup structure should be kept in the plant for checking purposes. It is recommended that the contract documents permit this full-sized unit, if it is approved, to be used in the job installation.

Where mockup units are not used, the manufacturer shall request the Architect-Engineer to inspect and approve (sign and date) initial production elements, where the scale difference between such elements and the project samples makes appearance determinations difficult. If molds are produced by casting or forming over a pattern, it is recommended that such patterns also be inspected and approved by the Architect-Engineer. To avoid possible later controversies, these approvals should precede a release for producprovals may upset normal plant operations and the job schedule.

Any modifications from the previously approved samples, made to facilitate production, should be brought to the attention of the Architect-Engineer immediately and meet with his approval before regular production is started. It should be noted that only minor changes can be incorporated in the finished texture of initial production elements, i.e., full-sized units.

Plant inspection by the Architect-Engineer or his agent during production should be encouraged. This helps to assure both the Architect-Engineer and the manufacturer that desired end results can and are being realized.

Section 2—Forms or Molds

5.2.1—Materials and Construction

Molds for architectural precast concrete products are tools of key importance and their manufacture requires a high degree of skill. All molds, regardless of material, shall conform to the shape, lines and dimensions shown on the approved erection drawings.

Forms or molds for architectural precast concrete can be made of various materials such as plywood, concrete, steel, plastics, polyester resins reinforced with glass fibers, plaster or a combination of these materials. For complicated details, molds of plaster, foam plastic, or sculptured sand have been used. These molds are often combined or reinforced with wood or steel depending on the size of the panel to be cast. The choice of material should be the manufacturer's and is determined by a combination of factors, among which are:

(1) Quantity of identical molds for one project.
(2) Number of castings per mold.
(3) Shape, size and finish of the precast concrete element.
(4) Method of consolidation of the concrete.
(5) Cost.
(6) Maintenance of mold.

Forms shall be dimensionally stable in use to produce the required degree of finish and tolerance. Repeated casting, consolidation and stripping shall not affect the dimensions or planes of the castings beyond permissible tolerances. In general, the form fabrication and set-up tolerances should be one-half of the tolerance of the units they are to produce, or a maximum of ± $1/8$ in. Window openings, especially, require that a high degree of accuracy be maintained and for glazing directly to concrete the plane of the opening must be constantly held to close tolerances. Form materials shall not warp or buckle because of temperature change or moisture, which will cause unsightly depressions and uneven swells in the finished surface. The form materials shall be non-absorbent or sealed to prevent moisture absorption in order to remove the possibility of local darkening of the surface and variations in water-cement ratio due to differential moisture movements resulting from varying degrees of absorbency.

Forms shall be built sufficiently rigid to provide dimensional stability during handling and sufficiently tight to prevent leakage of water or cement paste. Form seams resulting from joining of the form materials are to be eliminated to the extent that they will not be reflected in the concrete to mar the appearance of the finished surface of the precast unit. Loose parts, such as bulkheads, side or top forms, or any form modification pieces, shall be well fitted with joints sealed. Extra care shall be taken to attain and maintain form tightness where vibration is of the external type; even minute openings in the form will permit loss of grout. Welds on steel forms should be checked at least weekly.

Forms shall be sufficiently rigid to withstand the forces necessary for consolidating the concrete (both external and internal vibration), as well as the pressures developed by the plastic concrete, and shall be capable of transmitting the vibration over a considerable area in a more or less uniform manner.

Molds shall permit controlled, fixed positioning or jigging of hardware and allow for the suspension or placement of the reinforcing cage in a position that will maintain the specified concrete coverage on the reinforcement. Supports for molds shall be such that no undesirable movement can take place. As a rule, forms to be externally vibrated should be placed on 1½ to 2 in. thick 60 to 70 durometer rubber or neoprene isolation pads or other resilient base to prevent transmission and loss of vibration to the supporting foundation. This is also advantageous from the noise aspect.

Molds of *wood* should be sealed with resins or similar materials to prevent excessive absorption. Plywood may have a mill applied plastic overlay or be plastic coated. This will avoid a tendency to produce panels with non-uniform finish. The treatment also tends to stabilize the form dimensions. When wood sealers are used, a minimum of two coats are normally needed to ensure proper protection. A well applied wood sealer usually will hold up for a maximum of five reuses. After that, forms shall be sanded and retreated with sealer.

Periodic renovation of wooden molds is necessary, and special care should be exerted to assure that multiple use does not cause the mold to swell or bulge. Wood molds should not be used if live and joinery should be of such quality as to achieve joints which are not objectionable in appearance.

Concrete is well adapted as a form material for precast panels because it can be molded into practically any shape. In addition, it has excellent rigidity, dimensional stability, and a high number of reuses. Concrete molds are manufactured by casting over a master model fabricated to very close tolerances. This model may be used for the production of a series of identical molds. Concrete molds should be treated with epoxy, sealers or wax to reduce mold damage and to improve their ability to release the cast during the lifting operation. These non-absorbent coatings, by rendering the concrete non-absorbent, produce a uniform finish on the product. Concrete molds are also well adapted to prestressing by jacking against the mold. Since repairs of concrete molds are difficult, careful use of vibrators is required.

Particular effort should be made to provide adequate draft on all concrete mold surfaces in the direction of the release, so that the product may be easily removed without damage to either the panel or the mold. In some instances, several air outlets in the concrete mold for the introduction of compressed air between the mold and panel surface may be helpful in stripping. Molds should be cast with mixes as dry as practical concrete placement permits and thoroughly cured. Even very fine hairline cracks in the mold will be visible in the finished products with a smooth finish.

Steel molds are often selected for precast members when it is anticipated that numerous assemblies and disassemblies of the mold will be required. Properly designed steel molds have almost unlimited potential reusage; they need be discarded only when damaged, or when they show surface imperfections from drilling for changes or from cutting and alteration procedures.

Steel molds should be well braced and constantly examined for bulging or buckling. Dimpling, twisting, or bending may occur if they are not properly stacked for storage. Steel sheet used for a smooth surface should be oiled and pickled. When steel sheets are used for the base of the mold, it is desirable to use a single piece which has been "stretcher-leveled" in the steel plant. Joining of two or more steel sheets by welding is difficult due to distortion from the heat of the welding operation. If joining is required, the welds should be ground smooth and coated with an epoxy or similar material adequate to hide the joint. Bluing over welded material can be beneficial in avoiding staining from different surface characteristics. If this must be done, it is recommended that a test section be cast at the joint to determine that the joined area produces an acceptable product. If it is planned to apply a prestressing force by jacking against the form, the mold must be strong enough to resist the prestressing force without buckling or wrinkling.

Steel is the preferred forming material for external vibration because it has good structural strength and fatigue properties, is well suited for attachment of vibrators, and when properly reinforced provides good, uniform transmission of vibration. Heavy sheet steel (0.229 in. or 7 gage), stiffening with vertical or horizontal 2 x 2-in. ribs, or both should be used. Stiffeners are generally 4 in. on centers with spacing varying with loading and depth of section. The stiffeners help to distribute the vibrations evenly over the form surface. Stiffeners should extend the full length of the section to be vibrated and be welded using a low hydrogen rod, with 2-in. welds at 2-in. intervals. Oscillation (flexing) of the steel sheet between the stiffeners is normally somewhat greater than for the stiffeners themselves, but it should not be excessive if the stiffeners are closely spaced. Special members (such as steel I-beams or channels) should be placed next to the sheet, passing through the stiffeners in a continuous run. It is generally desirable to weld the stiffeners to these members. Welding at corners of vibrator mounting members or brackets should be avoided as this promotes angular crack propagation.

Fiberglass reinforced *plastic* molds produced from polyester and epoxy resins are finding considerable application because they can be molded into complicated shapes, and can impart a great variety of patterns to the finished product. Properly designed plastic molds have excellent performance and reuse expectancy. The surface of plastic molds may be renovated, periodically if necessary, when its finish deteriorates from usage. The surface is susceptible to damage from contact with internal vibrators. Plastic molds shall not be used when steam curing is anticipated. Also, the susceptibility of the plastic mold to attack by the proposed form oils shall be determined.

Fiberglass reinforced plastics have a fairly low modulus of elasticity and are somewhat flexible, even though they have excellent tensile strength. Even though a gel coat is used, unless alkali resistant glass fibers are used, deterioration can be expected when in contact with the concrete. Maintenance of the resin cover is mandatory for surface uniformity. It can be accomplished by careful cleaning, use of parting compounds, or occasional touch-up of the surface. If the mold is made entirely of plastic, it should be well supported along edges and flat areas. This may be accomplished by building-in reinforcement of lumber, steel shapes, or other mamold is frequently designed as a mold liner, and requires a "mother" mold for adequate support.

5.2.2.—Verification and Maintenance

The mold shall be checked in detail after its construction and before the first unit is made. A complete check of the first product from the mold is further verification of the adequacy of the mold. Checking by correlating product inspection of appearances and dimensional tolerances to the form is only feasible where an element can positively be identified with the specific form in which it was cast.

Molds shall be clean and in good condition between castings to provide a uniform product of high quality. Plugging of holes in the forms shall be done neatly so that finished members will have a satisfactory appearance. Steel forms must be carefully maintained if dye discoloration from iron oxides is to be avoided.

The forms shall be reassembled within the dimensional limitations specified for the product on the shop drawings. The squareness of the form shall be checked by comparing diagonal measurements to the corners of the form. Bulkheads, templates and similar equipment having influence on the accuracy of dimensions and alignment shall be regularly inspected and maintained as necessary. If more than one form is used to produce a given unit, a comparative dimensional check should be made.

All anchorage locations on the forms for holding any cast-in materials to a given position shall be checked to insure that continuous form use will not create wear and exceed tolerances. On wood molds, these clamp-on areas should be protected with face plates.

Joints may open, weldments come loose, rubber sealing strips erode; wood loses its protective coating, absorbs moisture and may swell or warp; and side rails bow due to daily production. It is therefore necessary to check the molds periodically for their soundness, surface and dimensional stability, and to repair damage before it affects the quality of the product.

Forms shall be cleaned thoroughly after each use to ensure that release agents will not build up and that joints between form parts will remain sealed.

Section 3—Reinforcement

5.3.1—General

Reinforcement in precast units shall be provided to resist, separately, each of the following groups of effects or combination of loading:

(1) Stripping from the form, plant handling, stockpiling, shipping and erection.
(2) Creep, shrinkage and temperature effects.
(3) Wind plus member's own weight and other gravity loads.
(4) Earthquake plus member's own weight and other gravity loads.

Reinforcement should be placed symmetrically near both faces in all panels to minimize bowing and distortion of panels. Nonsymmetrical placement may cause panel warpage due to restraint of drying shrinkage or temperature movements. Panels having a concrete thickness less than 6 in. may have reinforcement placed in one layer; however, two layers of equivalent weight are recommended to control concrete cracking.

The size and spacing of all reinforcement shall be checked against the approved erection drawings. Variations in spacing of reinforcement exceeding allowable tolerances must be corrected. The spacing of the reinforcing bars or wire fabric in the wall panels should not exceed twice the thickness of the panel. Where surface and shrinkage cracking must be minimized, the spacing of reinforcement should not exceed the panel thickness.

In general, the requirements for prestressing architectural members are those used for structural prestressed concrete. If prestressing is to be used, the recommendations in PCI MNL 116, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products,* shall be followed.

5.3.2—Fabrication

Welded wire fabric and reinforcing bars should be preassembled into cages using a template or jig before being placed in the forms, unless the precast unit is a simple flat panel. Cage assemblies, whether made for the entire casting or consisting of several subassemblies shall be constructed to close tolerances so that they fit into molds without being forced. Cages shall be sufficiently rigid to withstand handling and placing without losing their dimensional stability. Reinforcing cages also must be rigid enough to prevent dislocation during compaction in order to maintain the required cover over the reinforcement. Various pieces shall be rigidly connected by tying or welding.

Tie wire should preferably be soft stainless steel to avoid staining exposed surfaces; however, soft-annealed wire, #16 gage or heavier, is satisfactory. All tie wires shall be bent back away from formed surfaces to provide maximum cover.

The rigidity of a cage will normally improve with tack welding. However, welding of reinforcing bars should not be indiscriminately executed without regard to steel weldability and proper

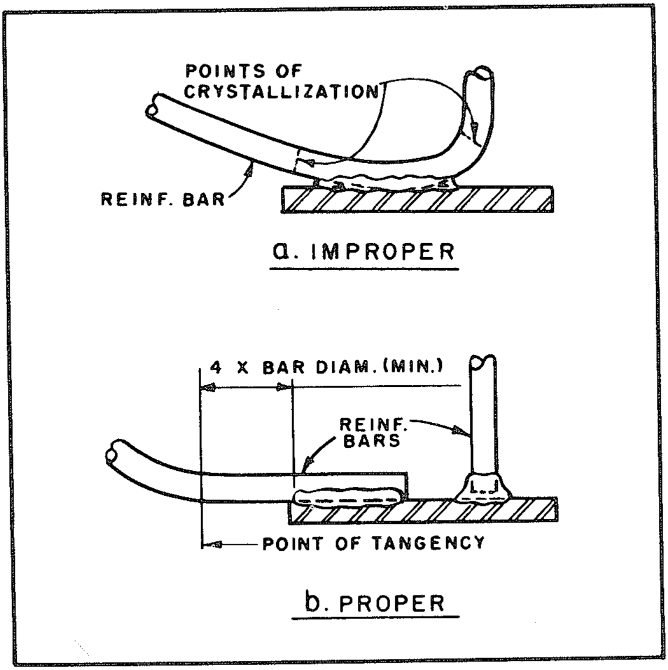
Carbon equivalent[3] range, percent	Size of reinforcing bar	Minimum preheat and interpass temperatures[1,2,5] deg F.	deg C
0.40 max.	Up to 11 inclusive	None[4]	
	14 and 18	50	10
0.41–0.45 inclusive	Up to 11 inclusive	None[4]	
	14 and 18	100	38
0.46–0.55 inclusive	Up to 6 inclusive	None[4]	
	7 to 11 inclusive	50	10
	14 and 18	200	93
0.56–0.65 inclusive	Up to 6 inclusive	100	38
	7 to 11 inclusive	200	93
	14 and 18	300	149
0.66–0.75 inclusive	Up to 6 inclusive	300	149
	7 to 18 inclusive	400	204
Above 0.75	Up to 9 inclusive	500	260
	10 to 18 inclusive	Use thermite or pressure gas only	

1. Note: When reinforcing steel is to be welded to main structural material, the preheat requirements of the structural material shall also be considered (see Table 4.2, AWS D1.1). The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables. However, extreme caution shall be exercised in the case of welding reinforcing steel to quenched and tempered steels and such measures shall be taken as to satisfy the preheat requirements for both. If not possible, welding shall not be used to join the two base metals.
   Welding shall not be done when the ambient temperature is lower than 0F (−18C). When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) by using glow torch in such a manner that the cross section of the bar for not less than 6 in. (152 mm) on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures must be sufficient to prevent crack formation.
2. After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.
3. Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75.
4. When the base metal is below 32F (0C), preheat the base metal to at least 70F (21C) and maintain this minimum temperature during welding.
5. Use Tempilstiks for determining preheat and interpass temperatures. (Tempil Corporation, 132 West 22nd Street, New York, N.Y. 10011)

welding procedures. Striking an arc outside of the weld area of the reinforcing bar shall not be permitted. Quality control shall mark heat numbers and carbon equivalent on tags for all bars (or bundles of bars), and all #10 bars or larger, with carbon equivalents above 0.75 percent, shall be tagged to read "not weldable." Welding procedures should be in conformance with AWS D12.1, *Reinforcing Steel Welding Code.* Table 3 gives preheat and interpass temperatures for manual arc welding of reinforcing bars. Certified welders shall be used for both tacking and structural welds.

Small tack welds are all that are required to give stability to reinforcing cages. Tack welding shall be allowed unless prohibited by the Architect-Engineer. A low heat setting shall be used to avoid undercutting the bars (diminishing the effective steel area). No tack welding within four bar diameters of a cold bend shall be permitted as this results in crystallization and unpredictable behavior of the reinforcing bar at the bend (see Fig. 4).

Surfaces of reinforcing bars to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease, or other foreign materials. Mill scale that withstands vigorous wire brushing, a thin rust inhibitive coating, or anti-spatter compound, may remain. All welds shall be slagged prior to concreting.



fumes, and removes the zinc coating in the area of the weld. When welding is carried out in confined spaces, ventilation shall be provided to remove fumes. When gaps are evident in the zinc coating, the coating can be repaired by application of a zinc-rich paint over the abrasive blasted surface.

Welding in the proximity of prestressing steel shall be avoided within a distance through which the spatter, direct heat, or short-circuited current may flow. The temperature rise due to the direct effect of welding heat or the indirect effect of current flow through the high tensile prestressing steel can cause a sudden strand rupture.

Quality control shall check each structural weldment visually for presence of cracks and other visual defects, in addition to checking that required weld size, length, location and type are as indicated on the approved drawings.

5.3.3—Installation

All reinforcement, at the time concrete is placed, shall be free of grease, oil, wax, dirt, paint, loose rust or mill scale, or other contaminants that may reduce bond between steel and concrete or stain the surface of the concrete.

Bar and mesh reinforcement shall be located accurately in the forms as indicated on the approved erection drawings and secured to maintain its designed location while concrete is placed and consolidated. Reinforcement cages should be securely suspended from the back of the molds, if spacers or chairs mar the finished surface of an element which will eventually be exposed to weathering or has an architectural finish. If spacers are used they shall be of a type and of material which will not cause spalling of the concrete, rust marking or other deleterious effects. Metal chairs, with or without coating, shall not be used in a finished face. For smooth cast facing, stainless steel chairs are tolerable, if specifically permitted in the specifications. Chairs should preferably be of stainless steel, plastic tipped or all-plastic to insure absence of surface rust staining.

Plastic-tipped chairs should be investigated for durability when exposed to the weather or sunlight. The coefficient of thermal expansion for some plastic material used to make all-plastic bar supports is considerably larger than that for concrete. For concrete which will be exposed to very high or low temperatures, or to a large range of temperatures, this characteristic of the material should be investigated. An alternative to suspending reinforcement, or the use of chairs in flat slabs, is to place the reinforcement on a layer of consolidated fresh concrete of the correct depth before placing the upper layer of the slab.

After reinforcement is set to its final position within the form, clearances or cover must be checked. Care is necessary in maintaining the critical dimensions determining the cover over reinforcement in order to reduce the chance of surface staining due to steel corrosion.

For exposed aggregate surfaces, the concrete cover to surface of steel should not be measured from the original surface; the typical depth of mortar removal between the pieces of coarse aggregate shall be subtracted. Attention must also be given to scoring, false joints, and drips; the required minimum cover shall be measured from the bottom of the groove to the reinforcement.

For concrete surfaces exposed to weather, reinforcement shall be protected by concrete cover equal to nominal diameter of bars but not less than:

3/4 in. for panel thicknesses greater than 3 in.
1/2 in. for panel thicknesses less than 3 in.

For concrete surfaces not exposed to weather, ground or water, all reinforcement shall be protected by concrete cover equal to nominal diameter of bars but not less than:

5/8 in. for panel thicknesses greater than 3 in.
3/8 in. for panel thicknesses less than 3 in.

Cover requirements over reinforcement shall be increased to 1 1/2 in. for non-galvanized reinforcement, or 3/4 in. with galvanized reinforcement when the precast elements are acid treated or exposed to a corrosive environment or to severe exposure conditions. In addition, the 3/4-in. cover is realistic only if the maximum aggregate size does not exceed 1/2 in.

When galvanized reinforcement is used in concrete it shall not be coupled directly to bare steel reinforcement, copper, or other dissimilar metal. Polyethylene or similar tapes can be used to provide local insulation between any dissimilar metals if desired.

Care shall be observed in placing of bars which extend out of the member and which are intended to provide structural connection for cast-in-place connections. Improper extension could result in a weak joint. Normally, the extensions should be within ±1/2 in. of plan dimensions. Paste adhering to extended steel shall be removed.

Unless permitted by the Architect-Engineer, reinforcement shall not be bent after being embedded in hardened concrete. Partially embedded reinforcing bars can be successfully rebent (or bent for the first time, which should be less critical) if they are first preheated to 1100 to 1200 F and then bent as gently and in as gradual an arc as possible.

The heating operation should be conducted in such a manner that the temperature of the steel does not exceed 1200 F as measured forced air) until after cooling to at least 600°F. If there is no failure at the bend area, the reworked bars should perform as originally intended. Heating must be performed in a manner that will avoid damage to the concrete. If the bend area is within 6 in. or so of the concrete, some protective insulation may have to be applied.

If reinforcing steel or hardware anchors cannot be located as shown on drawings, all changes shall be approved by the Engineering Department and drawings in turn corrected to show the as-cast position. Under no circumstances shall main reinforcement be eliminated to accommodate hardware. Proper reinforcement of concrete close to anchors, on which hardware units rely for anchorage, shall also be provided and maintained.

Section 4—Hardware

5.4.1—Installation

All hardware connections, inserts, and handling and lifting devices shall be checked prior to casting to verify that they are accounted for and accurately located as detailed on the erection drawings within established tolerances. It is recommended that hardware become a part of the reinforcing cage or otherwise be properly jigged for accurate location. Inserts must be placed accurately because their capacity decreases sharply if they are not perpendicular to the bearing surface, or if they are not in a straight line with the applied force. It is equally important to place inserts so that the depth of thread is constant for the same size insert throughout a particular job. Otherwise an erection crew may make mistakes in the field by not always catching the full thread (see Fig. 5).

Special attention should be given to vertical dimensions to avoid unnecessary and costly alignments in the field. Bearing surfaces of panel hardware and matching hardware on the structure should be parallel to obtain optimum bearing or load transfer.

Hardware shall be firmly held in position, during placement and consolidation of the concrete, by jigs, beams, templates, mold brackets, or stiffbacks. Hardware should have provisions for holes, lugs, nuts, etc. so that they may be secured to their support.

When items cast into panels are specified to be plated, galvanized or of stainless steel, a check to insure that the material is of the proper type or coating shall be made.

Embedded anchors, inserts, plates, angles, and other cast-in items shall have sufficient anchorage and embedment for proper stress distribution and shall be fastened to the reinforcement,

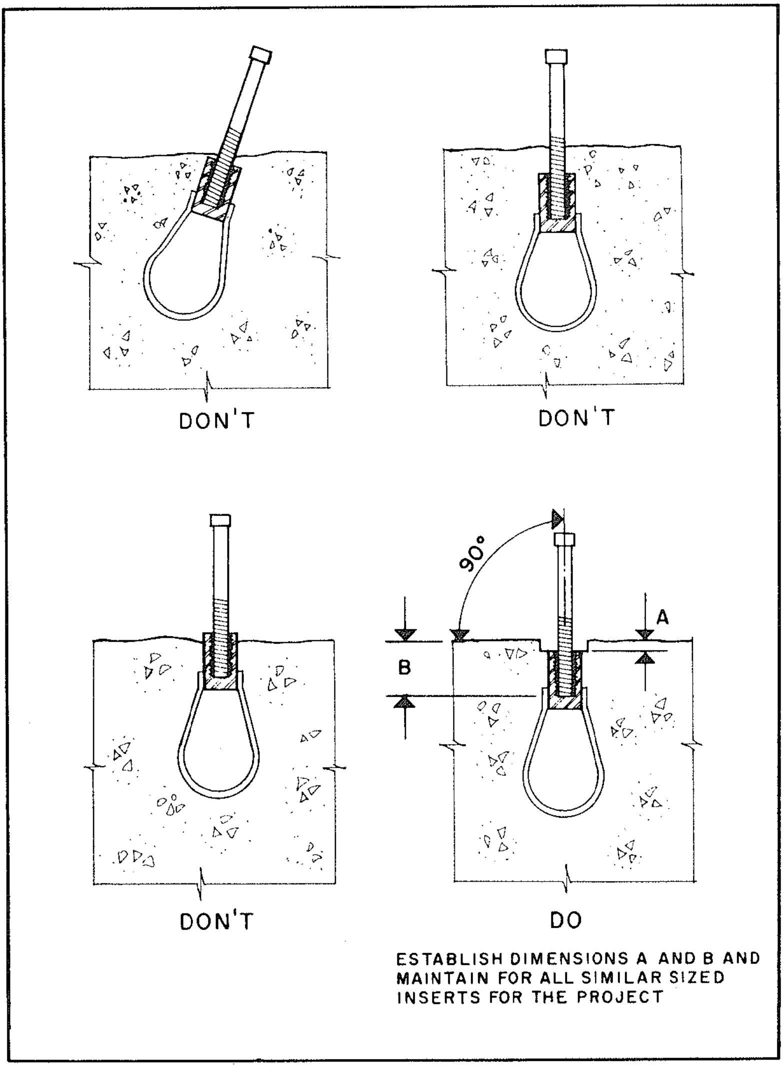

DON'T
DON'T
DON'T
DO
90°
A
B
ESTABLISH DIMENSIONS A AND B AND MAINTAIN FOR ALL SIMILAR SIZED INSERTS FOR THE PROJECT

Fig. 5. Improper and proper methods of placing inserts

wherever possible. Anchorage may be obtained through mild steel or reinforcing dowels, studs, loops of flat bars, angles, or a combination of these.

Where plates or angles are positioned so that concrete has to be worked under them, entrapment of air as the unit is cast may result in honeycombing or voids. For these situations, air-release holes shall be provided in the horizontal portion of the embedment, so that entrapped air can escape.

Hardware having structural significance shall be welded in accordance with *Reinforcing Steel Welding Code* (AWS D12.1).

(plates or angles), the preheat requirements of the structural material shall also be considered (see Table 4.2 in AWS D1.1–72). The minimum preheat requirement to apply in this situation shall be the higher requirement. When preheat is required, determine the appropriate temperature with Tempilstik. (Crayon mark will melt when specified temperature is reached.) Weldments shall be checked after fabrication for brittleness by striking at least one out of every 50 pieces with a hammer. Brittle weldments break under a hammer blow and if brittle weldment is found, the entire batch must be checked.

Studs used for anchorage shall be prepared in accordance with AWS D1.1. Before starting the welding day, two studs (headed concrete anchors or deformed bar anchors) shall be welded to the hardware and, after being allowed to cool, tested by striking them with a hammer and by bending them at a 30-deg. angle from their original axis. If failure occurs in the weld zone of either stud, the welding procedure shall be corrected and two successive studs successfully welded and tested before any studs are welded for production use. The foregoing testing shall also be performed after any change in the welding procedure.

Studs on which a full 360-deg. weld fillet is not obtained may be repaired by adding a 3/16-in. minimum fillet weld in place of the missing weld using the shield metal-arc process with low hydrogen welding electrode. The repair weld shall extend 3/8 in. minimum beyond each end of defect being repaired.

If the reduction in length of studs as they are welded becomes less than normal for that diameter of stud, i.e., the length of stud is more than 1/16 in. greater than specified, welding shall be stopped immediately and not resumed until the cause has been corrected.

When approved by the plant engineer, embedded items such as dowels or inserts, that either protrude from the concrete or remain exposed for inspection, may be installed while the concrete is in a plastic state provided they are not required to be hooked or tied to reinforcement within the concrete and they are maintained in correct position while the concrete remains plastic. Such items shall be properly anchored to develop the design loads. The concrete surface adjacent to the item should be flat and well finished for proper bearing and the item should be placed perpendicular to this surface.

Voids in sleeves, inserts, and anchor slots shall be filled temporarily with readily removable material to prevent entry of concrete into voids.

The installation of inserts and fastenings by explosive actuated or power driven tools shall only be allowed where such installation will not damage the structural integrity of the units by being too close to reinforcement or strands, or mar the finish by causing spalling, chipping or cracking of unit.

A shop coat of non-toxic paint should be applied to all exposed surfaces of weld plates and retouched after welding. Weld plates should be inspected before concrete placement to ensure that anchors are securely welded to the plates.

Lifting devices should be located on architecturally less prominent surfaces. Otherwise, cutting off, patching, and filling operations may become expensive. All inserts which are on an exposed face should be checked to insure that they are properly recessed for future patching.

Section 5—Concrete Casting

5.5.1—Mix Proportioning

Much of the skill, knowledge and technique of producing quality architectural precast concrete centers around the proper proportioning of the mix. Before a concrete mix can be properly proportioned, several factors must be known. The finish, size and shapes of units to be cast must be considered. The method of consolidation must be known to determine the required workability. The maximum size of the coarse aggregate must be established. The required compressive strength affects the amount of cement to be used as well as the maximum water allowed. The required surface finish frequently will control the ratio of coarse to fine aggregate. The extent of exposure to severe weather will affect the durability requirements of the concrete proportioning.

Concrete mixes for precast concrete must be established initially by laboratory methods. The proportioning of mixes may be done either by a qualified commercial laboratory or precast concrete plant personnel. Mixes shall be evaluated by trial and field tests under conditions simulating actual production as closely as possible. Tests will be necessary on all mixes including face, backup and standard, which may be used in production of units. When accelerated curing is to be used, it is advisable to base the mix proportions on similarly cured test specimens.

Accepted methods of mix proportioning are given in detail in the following publications:

(1) Portland Cement Association:
    (a) *Design and Control of Concrete Mixtures.*
(2) American Concrete Institute:
    (a) *Recommended Practice for Selecting Proportions for Normal and Heavy Weight Concrete* (ACI 211.1).
    (b) *Recommended Practice for Selecting Proportions for Structural Lightweight Concrete* (ACI 211.2).

time any of these variables are changed the proposed mix shall be re-evaluated.

Concrete mixes should be proportioned and/or evaluated for each individual project with respect to strength, absorption and resistance to freezing and thawing where such environments exist, and volume constancy as well as effects on surface finish. At the same time, the mix should have adequate workability for proper placement and consolidation.

Concrete strength and durability are achieved through proper consideration in mix design of density, water and cement content, and workability. Low water-cement ratios lead to improved strength and durability and low absorption. Drying shrinkage characteristics are affected by aggregate size, gradation, mineralogy, aggregate-cement ratios, cement factors, water-cement ratios, additives, and admixtures; all of these must be considered.

Concrete strengths are usually specified in terms of compressive strengths, determined on test specimens either at time of stripping or at a specified age, usually 28 days, although other ages may be specified.

For commonly used concrete mixes such as structural and backup mixes, or for face mixes where the size of the project warrants, a plant shall maintain an up-to-date knowledge of the variability of their concrete production. Based on this information, an actual design strength shall be chosen for the concrete which will comply with the statistical interpretation of the strength requirements given in ACI 318.

The strength level of the concrete will be considered satisfactory as long as the average of any three consecutive strength tests equals or exceeds the specified strength and no individual test falls below the specified strength by more than 500 psi. Strength tests failing to meet these criteria will occur occasionally (probably about once in 100 tests), even though strength level and uniformity are satisfactory. Allowance should be made for such statistically normal deviations in deciding whether or not the strength level being produced is adequate.

Adequate statistical records are based on at least 30 consecutive strength tests obtained within the past year representing similar materials and conditions to those expected. The 30 consecutive strength tests may represent either a group of 30 consecutive batches of the same class of concrete or the statistical average for two groups totaling 30 or more batches.

Average strengths, used as the basis for selecting proportions, shall exceed the specified strength by at least:

400 psi if the standard deviation is less than 300 psi.
550 psi if the standard deviation is 300 to 400 psi.
700 psi if the standard deviation is 400 to 500 psi.
900 psi if the standard deviation is 500 to 600 psi.

If the standard deviation exceeds 600 psi or if a suitable record of strength test performance is not available, proportions shall be selected to produce an average strength at least 1200 psi greater than the specified strength.

Concrete, including face and backup concrete, used in precast units should normally have a specified compressive strength of 5000 psi at 28 days as determined by cylinders or 6250 psi when determined by 4-in. cubes. This strength normally satisfies production requirements and also assures proper durability. The strength requirements for face mixes and backup mixes may differ. The strength at time of removal from the mold should be stated if it is critical to the engineering design of the units. When panels are prestressed, the concrete should have a specified compressive strength of at least 3000 psi at time of transfer of prestress and 5000 psi at 28 days.

In cases where the 5000-psi strength is not structurally necessary, or may be difficult to attain due to special cements or aggregates, sufficient durability and weathering qualities may be obtained by stating proper air entrainment and absorption limits at a strength level as low as 4000 psi.

All combinations of cement and aggregates shall be those for which chemical and physical properties or long experience have shown conclusively that the various components are compatible and will not result in serious volume changes, cracking or deterioration of the concrete as it ages. In particular, the use of high alkali cement together with alkali reactive aggregates shall be avoided. Also to be avoided are aggregates subject to "pop-outs" or other surface deterioration. These precautions are particularly necessary in areas subject to freezing and thawing or in locations where strong salt or sulfate exposures are expected.

As a control measure for staining of concrete due to weathering, it is recommended that maximum water absorption limits be established [see Article 2.1.2(9)(b)]. Low absorption for the surface concrete demands a high density of concrete.

Air entrainment is recommended for units subject to freezing and thawing. Because of the gradation characteristics of most facing mix concrete, a given percentage of air cannot be specified for these mixes. Instead, use of air-entraining agent to provide a "normal" dosage is recommended. Normal dosage of air-entraining agent shall produce an 8 to 10 percent air content when tested in accordance with ASTM C 185, but using only the mortar (material sizes of coarse aggregate

Nominal maximum size of coarse aggregate, in.	Total air content, percent by volume
⅜	6 to 10
½	5 to 9
¾	4 to 8
1	3.5 to 6.5

less than ¼ in.) portion of the mix. Once established for the mixture, the corresponding entrained air content of the total concrete mixture may be determined, and that value used in production control.

When a specific level of air content can be maintained in concrete units exposed to freeze-thaw, deicer and wet-dry conditions, see Table 4 for recommended amounts. For any given set of conditions and materials, the amount of air entrained is roughly proportional to the quantity of agent used. However, in some cases a ceiling may be reached and it may be necessary to change the type of air-entraining admixture or to achieve the desired result some other way (e.g., change the cement).

For the same water-cement ratio, air entrainment will usually result in about 10 percent reduction of concrete strength. The added protection that controlled amounts of entrained air provide against freezing and thawing deterioration far outweighs any slight loss of strength or density.

Where a precast unit consists of a face and backup mix, the mixes should have reasonably similar shrinkage, thermal coefficients of expansion, and modulus of elasticity to avoid undue bowing or warping. Consequently, these mixes should have similar water-cement and aggregate-cement ratios.

The combination of a normal weight face mix and a backup with lightweight aggregates may increase the possibility of bowing or warping. Before using such a combination, pilot units, produced and stored under anticipated production conditions, are often desirable to verify performance.

The face mix for architectural concrete units shall be designed to produce the desired appearance taking into account the technique for obtaining this finish. The type of finish to be achieved is the key factor to consider when making the decision regarding the quantity of coarse aggregate desired in the architectural concrete mix. The material requirements will vary with the depth and amount of surface removed. The shallower the surface, the more influence the aggregate fines and cement will have, and the deeper the surface the more influence the coarse aggregate will have.

The water-cement ratio shall not exceed 0.45 by weight with an allowable variation during production of ±0.02. This may be too high for some applications. In all mix designs for precast concrete production the importance of a low water-cement ratio shall be recognized, but this ratio must also be evaluated in relation to the workability required for satisfactory placing and consolidation techniques for the actual mix application. Any water used above the absolute minimum needed for placing may cause segregation and paste accumulations which in turn may result in imperfections in the exposed aggregate surface.

It is difficult to recommend a slump for precast concrete production. Very stiff mixes require more labor to place and special vibration techniques. Therefore, the slump and workability of a mix should be suitable for the conditions of each individual job, i.e., to permit the concrete to be worked readily into the forms and around reinforcement under the conditions of placement to be used, without excessive segregation or bleeding. This usually relates to the shape of the unit, height of casting, the amount and complexity of reinforcement, and the method of consolidation.

In general, the slump should be as low as possible and constant from batch to batch in order to provide uniformity of color in the end product. Architectural concrete slumps should not exceed 3 in. in most instances. Gap-graded mixes should generally not have slumps greater than 2 in. Slumps higher than this increase the probability of segregation. Slump tolerances of ±1 in. should be maintained for color control of smooth concrete surfaces.

5.5.2—Batching and Mixing

In addition to accurate measurement of materials (see Article 3.2.4), correct operating procedures must also be used if concrete uniformity is to be maintained. Care should be taken to insure that the weighed materials are properly sequenced and blended during charging of the mixers. This will contribute significantly toward the maintenance of batch-to-batch uniformity.

Information on mix designs shall be recorded and kept at the batching plant.

Fine and coarse aggregates as delivered to the weigh batchers should be of good quality and uniform in grading and moisture content. Segregation in coarse aggregate should be reduced to a practical minimum by separating the material into several size fractions and batching these fractions separately. As the range of sizes in each fraction is decreased and the number of size separations is increased, segregation is further reduced. Effective control when the ratio of maximum to minimum size in each fraction is held to not more than four for aggregates smaller than 1 in. diameter and to two for larger sizes.

Fine and coarse aggregates, cement, coloring pigments and powdered admixtures shall be measured by weight. Aggregate batch weights shall include an allowance for free moisture in the aggregates. Standard 94-lb. bags of cement may be used without weighing but any fractional bags shall be weighed. Water and liquid admixtures may be measured either by weight or volume. Weights of normal weight aggregates shall be based on saturated-surface dry condition corrected for free surface moisture. Weights of lightweight aggregates shall be based on oven-dry weights corrected for absorbed moisture or absorbed moisture plus surface moisture.

All concrete materials shall be discharged to the mixer while the drum or blades are rotating. In the discharge of component materials from batching facilities to the mixer, the solid materials should, if possible, be arranged in the charging hoppers so proportional amounts of each would be ribbon fed to the mixer. Cement and coloring pigments shall be charged with the fine and coarse aggregates but should enter the stream after approximately 10 percent of the aggregate is in the mixer. Free fall of cement shall not be permitted. Cement shall flow from its hopper into the stream of aggregates through a suitable enclosure chute, usually a tube of canvas or rubber. Materials should enter the mixer at a point near the center of the mixer.

When mixing normal weight concrete, a portion of the mixing water, between 5 and 10 percent, should precede and a like quantity should follow, discharge of other materials, within the first 25 percent of the mixing time. The remainder of the water should be introduced uniformly with other materials. Where mixers of 1 cu. yd. capacity or less are used, the aggregates may be placed into the mixer first and then the cement and water introduced at the same time.

Lightweight aggregate concrete should be batched and mixed as recommended by the producer of the aggregate. With aggregates of low absorption, prewetting prior to mixing is not required; with others, prewetting to as uniform a moisture content as possible, or premixing with water prior to addition of the other ingredients of the concrete, may be done to maintain the proportioned volume of the concrete and minimize slump loss due to rapid absorption of mixing water.

The lightweight aggregate (and sand if used) and about 80 percent of the mixing water should be placed in the mixer and mixed thoroughly. Then the admixtures, if any, the entire weight of cement and the remainder of the water should be added and mixing completed.

Admixtures should be discharged in accordance with the manufacturer's recommendations. Regardless of whether in liquid, paste or powdered form, the introduction of admixtures should generally be at a rate proportional to that of the other materials to insure uniform incorporation into the mix.

Admixtures should be charged to the mixer at the same point in the mixing sequence batch after batch. For some admixture-cement combinations, varying the time at which they are added during mixing may result in varying degrees of retardation or acceleration, or significantly affect the water requirement of the mixture. Liquid chemical admixtures should not be added directly to the cement or to dry, absorptive aggregate. Liquid admixtures should, in most cases, be charged with the last portion of mixing water. The entire amount of admixture should be added prior to the completion of the addition of the mixing water. Addition of retarding admixtures shall be completed within 1 min. after addition of water to the cement has been completed, or prior to the beginning of the last three-quarters of the required mixing, whichever occurs first.

When finely divided mineral admixtures are used in bulk, a weighing sequence of cement first and admixture second is recommended. This procedure should be followed when cement and finely divided mineral admixtures are weighed cumulatively on the same scale beam. Pigments should be preweighed and batched from packages that are of a size appropriate for a single batch. Mineral admixtures should not be charged into a wet mixer ahead of the other materials because of a tendency to stick to the sides of the mixer drum. Likewise, they should not be charged into the mixer along with the mixing water because of their tendency to ball up under such conditions.

Concrete of satisfactory quality requires the materials to be thoroughly mixed until there is a uniform distribution of the materials and the mix is uniform in appearance. The necessary time for mixing will depend on many factors including batch size, stiffness of the batch, size and grading of the aggregate, type of mixer, condition of blades, and the ability of the mixer to produce uniform concrete throughout the batch and from batch to batch. The most positive control method for maintaining batch-to-batch uniformity is a regularly scheduled program of tests of the fresh concrete including unit weight, air content, slump, and temperature. Strength tests are not used for this purpose.

Batch-to-batch uniformity of concrete from a mixer, particularly with regard to slump, water requirement, and air content also fore, important that maximum (90 F) and minimum ([illegible] F) concrete temperatures be controlled throughout all seasons of the year. Also, to help provide for products of uniform color, concrete temperatures shall be as uniform as practicable from one batch of concrete to another for the same project.

Materials should be free from ice, snow and frozen lumps before entering the mixer. When exposure to cold weather is severe, due either to low air temperature, or because the concrete sections are thin, the temperature of concrete shall approach the upper limit of 90 F. To accomplish this, the mixing water and, if necessary, the fine aggregates shall be heated. Aggregates shall not be heated above 180 F.

To avoid the possibility of flash set of the cement when either water or aggregate is heated to a temperature over 100 F, water and aggregate shall come together first in the mixer so that the temperature of the combination is reduced below 100 F before the cement is added.

If, due to high temperature, low slump, flash set or cold joints are encountered, the ingredients shall be cooled before mixing, or flake ice or well-crushed ice of a size that will melt completely during mixing may be substituted for all or part of the mixing water.

A mixer shall not be used to mix quantities greater than those recommended by the mixer manufacturer. Mixers shall be equipped with rating plates prominently displayed stating the rated capacity. The rate of rotation of drum or blades for stationary or truck mixers shall be in accordance with manufacturer's recommendations, designated on the name plate.

The mixing time for each batch after all materials are in the mixer should be uniform. For each type of mixer, the optimum mixing time shall be established by manufacturer's recommendations, or mixer performance shall be determined by the following tests using two samples, one taken after discharge of approximately 15 percent and the other after 85 percent of the batch:

(1) Unit weights of air-free mortar from the two samples shall not vary more than 1.6 percent from the average of the two mortar weights.

(2) Weights of coarse aggregate from the two samples, retained on a No. 4 screen, shall not vary more than 6 percent from the average of the two weights of coarse aggregate.

Generally, for stationary mixers, the minimum mixing time shall be one minute for batches of 1 cu. yd. or less. This mixing time shall be increased by at least 15 seconds for each cubic yard, or fraction thereof, of capacity in excess of 1 cu. yd. The mixing time should be increased when necessary to secure the required uniformity, particularly for colored concrete, and consistency of the concrete, but mixing time should not exceed three times the specified time. In case a batch has to be held in the mixer for a longer period, the speed of the drum or blades should, when possible, be reduced to an agitating rate.

For mixing in a truck mixer loaded to its maximum capacity, the number of revolutions of the drum or blades at mixing speed should be not less than 70 nor more than 100. If the batch is at least ½ cu. yd. less than the maximum capacity, the number of revolutions at mixing speed may be reduced to 50. All revolutions in excess of 100 should be at agitating speed.

When a stationary mixer is used for partial mixing of the concrete, the time may be reduced to about 30 seconds, followed by not less than 50 or more than 100 revolutions at mixing speed in a truck mixer. Any additional revolutions in the truck mixer should be at agitating speed.

When a truck mixer or agitator is used for transporting fully-mixed concrete, further mixing during transportation should be at agitating speed.

Controls should be provided to insure that the batch cannot be discharged until the required mixing time has elapsed and to prevent batched ingredients from entering the mixer before the previous batch has been completely discharged.

All recommendations and requirements for mixing of concrete as given in this article are valid for both normal weight aggregates as specified in ASTM C 33 and for lightweight aggregates for structural concrete as specified in ASTM C 330. When lightweight concrete is used for the first time, it is recommended the mixture and handling procedures be checked to make sure they are adequate to produce uniform concrete of the qualities specified. In such a case, the aggregate producer's recommendations are particularly helpful.

Mixers shall be capable of discharging concrete of the lowest slump suitable for the product being produced, without segregation.

When colored concrete, or buff or white cement mixes are used in conjunction with gray concrete—e.g., with facing and backup mixes—separate mixers and handling arrangements are required. Alternatively, the equipment shall be water flushed several times and completely cleaned to remove all concrete residue before being used for facing concrete.

All mechanical details of mixers or agitators shall be checked frequently (see Article 3.2.5). Oil should not be used to clean either contamination of the concrete or aggregates by oil spillage or leakage.

5.5.3—Placing

Proven procedures for placing concrete are described in detail in the following publications of the American Concrete Institute:

(1) *Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete* (ACI 304–73).

(2) *Recommended Practice for Hot Weather Concreting* (ACI 305–72).

(3) *Recommended Practice for Cold Weather Concreting* (ACI 306–72).

The provisions of these publications which are particularly applicable to the production of precast concrete units are given hereafter; however, these publications shall be available in precast concrete plants and supervisory personnel shall be familiar with their contents and insist on close adherence to the proven procedures listed therein.

Just prior to concreting, the form shall be cleaned and any unwanted materials should be removed by compressed air or vacuum cleaning. Before placing either reinforcing steel or concrete, a form-release agent shall be carefully and uniformly applied to all form surfaces that will be in contact with the concrete to provide easy release and stripping of the element from the form consistent with the required finish.

Form-release agents containing volatile solvents must be stored in airtight containers to prevent a change in concentration. One or two different agents should be evaluated by casting small-scale trial batches to find the one that best suits job conditions and produces acceptable finishes. One brand or batch of form-release agent should be used throughout a project.

The final assessment of any placing technique shall be the quality of the end product. Only those methods and arrangements of equipment shall be used which result in placing concrete in a uniform, compacted condition without separation of coarse aggregate and paste. Although scattered pieces of coarse aggregate are not objectionable, clusters and pockets of coarse aggregate are objectionable and should be scattered prior to placing concrete over them to prevent rock pockets and honeycomb in the completed work. It is a common fallacy to believe that segregated aggregate will be eliminated by subsequent placing and consolidation operations. The quality of the concrete, in terms of water-cement ratio, slump, air content, and homogeneity must be preserved.

Placing equipment shall be capable of handling concrete of specified proportions so it can be readily consolidated by vibration. Account should be taken of any special degree of harshness or stiffness of the mixes used, of any unusual variations in shape and position of casting, and of obstructions resulting from any unusual items to be cast into the concrete. The assessment of any special method or procedure shall be the uniformity and the quality of the end product.

Objection is occasionally made to a relatively low-slump concrete, particularly gap-graded concrete, which will not flow down a chute, drop out of a bucket or hopper, or discharge through gates, although it is readily workable in place when properly vibrated. Such an objection is not valid if the slump has been determined to be of practicable workability in the forms and has been made a requirement of the specifications. It is the function of concrete handling and placing equipment to handle and place concrete of proportions and consistencies that can be properly consolidated by vibration or other means. Limitations on consistencies and proportions shall not be imposed by inadequate chutes, hoppers, buckets or gates. For the units normally manufactured in precast concrete plants, and with vibrated placement, the lowest slump for practical placement should always be used.

It is important, in the design and approval of concrete handling equipment, that chutes be amply steep, metal or metal lined, round bottomed, of large size, rigid, and protected from overflow. Discharge gates, bucket openings and hoppers shall be large enough to pass quickly and freely concrete of the lowest slump likely to be found practicable for placing in the forms by means of vibration. In many cases chutes steeper than 2 horizontal to 1 vertical should be used, and double or triple the usual area of hopper outlets and gates will not be excessive.

The vertical drop when discharging concrete from mixer to conveying equipment should be kept to a minimum but not to exceed 5 ft. Concrete shall be transported from the mixer to the forms or molds in the shortest possible time and in such a manner as to prevent segregation or loss of mortar. Conveying equipment may be buggies, buckets, hoppers, conveyors or truck mixers.

Use of properly designed bottom dump buckets or hoppers permits placement of concrete at lowest practical slump consistent with consolidation by vibration. Discharge gates should have a clear opening no less than one-third the maximum interior horizontal area or five times the maximum aggregate size being used. Side slopes should be steep, being no less than 60 deg. with the horizontal. Controls on the gates should permit personnel to open and close them during any portion of the discharge cycle.

Belt conveyors shall be horizontal or at a slope which will not arrangement shall be used at the discharge end to prevent apparent segregation. Mortar shall not be allowed to adhere to the return length of the belt. Long runs shall be discharged into a hopper or through a baffle.

All conveying equipment shall be thoroughly cleaned at frequent intervals during a prolonged casting, between casting of different mixtures, or between stages of the same units such as between facing mix and backup concrete. Before the beginning of a new run of concrete, all hardened concrete and foreign matter shall be removed from the surfaces of the equipment involved.

Regardless of the manner of transportation, concrete shall be discharged into the forms while in its original mixed or plastic state. Retempering by adding water and remixing concrete which has started to stiffen shall not be permitted.

Sufficient mixing and placing capacity shall be provided so the products are free from cold joints or a plane of separation. If delays occur which result in hardening of the concrete so it will not receive a vibrator and again become plastic, partially filled forms shall be washed out or partially cast units rejected. To produce a monolithic and sightly placement, it is important each layer of concrete be shallow enough so it may be placed while the previous layer is still plastic and the two layers be vibrated together. If the depth exceeds 12 in., it is best to use two or more layers. The consistency of the concrete and surface appearance desired will also affect the method employed; the lower the water-cement ratio, the shallower the lift that should be used. Bonding between backup and face mix should be assured if backup concrete is cast before the face mix has attained its initial set. The thickness of a face mix after consolidation shall be at least 1 in. or a minimum of 1½ times the maximum size of the aggregate, whichever is larger; a face mix should be thick enough to prevent any backup concrete from showing on the exposed face.

In the case of large aggregates being hand laid in the mold, the size of aggregates shall govern the concrete mix used as the matrix. The 1-in. dimension is chosen because the consolidated face is normally used to provide the proper concrete cover over the reinforcement. For units not exposed to weather or for face mixes applied face-up, this dimension may be reduced to ¾ in.

Facing concrete should be carefully placed and worked into all details of the form. This is particularly important in external and internal corners for true and sharp casting lines. Each batch of concrete shall be placed as nearly as possible, in final position, adjacent to the preceding and following batch and the whole mass consolidated by vibration with as little shifting as possible. When a wet or semi-damp retarder is used, the concrete should not be slid over the form in such a manner that it would disturb the retarder. Concrete placing on a slope shall begin at the lower end of the slope and progress upward thereby increasing compaction of the concrete.

When placing the initial concrete mix, care shall be taken to avoid coating the reinforcement with cement paste which may endanger proper bonding in the second stage of concreting. Where this coating cannot be prevented, the placing of the backup concrete mix shall be done prior to the hardening of such coating, or it shall be cleaned off.

For deep, flanged members, some delay between the concrete placement in the web and placement in the flange will permit settlement of web concrete. This will reduce the restraint cracking which can occur at junction of flange and web.

Where an aggregate or finished face material changes within a panel, a definite feature (demarcation strip) should be inserted into the panel face to facilitate casting and to achieve a straight line joint between finishes. Two concrete mixes with different colored matrices exposed at the face of the panel should not be used within one unit. No demarcation feature can prevent a white cement paste from leaking into a gray or vice versa. Such mixtures are acceptable (although at added cost) where one part of the panel (for instance a spandrel part) is cast first of the one mix and, after curing, is cast into the total panel. This method has been successfully used by proper sealing of the cold joint and by providing special protection to the initially cast concrete element.

Concrete as placed should be at a temperature between 50 and 90 F. Optimum concrete temperature for placing is recommended as 70 F. Special precautions shall be observed in hot weather (when air temperatures are above 80 F) or in cold weather (below 40 F) during concreting operations so that the concrete remains plastic for a suitable placing and finishing period and then gains strength under favorable curing conditions. The form or mold temperature should be about the same as the concrete temperature. An optimum of 75 F to 80 F is desirable. It is more important that the temperatures remain constant throughout the project rather than whether they are near the upper or lower level of a temperature range.

For concrete placed in hot weather under cover, the only precaution generally required is to insure the temperature of concrete at time of placing is not above 90 F and to supply adequate moisture during the curing period to prevent surface drying.

When the ambient temperature is above 80 F, cracking of concrete or loss of strength, or both, may occur. If such conditions do be used as necessary to correct these deficiencies.

(1) Shaded storage for aggregates.
(2) Sprinkling or fog spraying of aggregates.
(3) Burying, insulating or shading water-supply facilities.
(4) Use of shaved or crushed ice for a portion of the mixing water. Only so much ice shall be used as will be entirely melted at the completion of the mixing period.
(5) Maintaining concrete surfaces in a cool and moist condition by use of coverings such as wet burlap or by sprinkling or ponding as soon as exposed concrete surfaces are finished, or as soon as water sheen disappears. This is especially important for hot, windy, exposed locations.
(6) White pigmented membranes may be used but are not recommended in very hot weather for the first 24 hrs. after casting since they do not cool the concrete as much as wet curing methods.
(7) A set-retarding admixture included in the concrete mix may delay concrete setting time in hot weather and give a longer period for placing and finishing.

5.5.4—Consolidation

Concrete used in architectural precast units should be uniformly consolidated by internal, or external vibration, by impact, or a combination of these methods. The end objective is to consolidate the concrete into a dense, uniform mass with an imperfection-free surface.

For the low-slump mixes commonly required to develop high early strength for precast concrete units, under-vibration is a more probable source of poor products than over-vibration; the mixes may be consolidated with little danger of segregation except in deep returns. The concrete mix has considerable effect on the vibration requirements. Air entrainment makes the mix a little stickier and a little more vibration is necessary to get the concrete properly compacted. Gap-graded mixes usually require more vibration to assure proper compaction and elimination of honeycomb areas. Consolidation of the concrete mix should accomplish full coating of the coarse aggregate and reinforcement with cement paste. Air pockets around uncoated reinforcement create a potential corrosive environment.

The selection of the best vibrator or vibration method involves factors such as:

(1) Size, shape, type and stiffness of molds.
(2) Concrete mix and consistency.
(3) Plant preference based on experience.

After the proper equipment has been selected, it should be operated by conscientious and well-trained operators who will consistently maintain the proper spacing and vibration times, and who understand when the concrete is adequately consolidated.

At present, there is no quick and fully reliable indicator for determining when adequate consolidation has been achieved. Adequacy of vibration may be gaged by (1) general leveling of the batch and a thin film of glistening mortar on the surface, (2) general cessation in escape of large bubbles of entrapped air at the top surface, except near the edge of the form, and (3) an experienced operator who learns the proper "feel" of an internal vibrator when consolidation is complete.

To obtain the maximum vibration effect and to avoid damage to vibrators and forms, it is important that the external vibrators be rigidly fixed to the forms. During the casting operation, a check shall be made to verify that the form clamps are tight and that the vibrators are in operation and firmly in place.

Internal vibrators shall not be used to consolidate face mixes. Backup concrete should normally be deposited in layers 12 to 18 in. thick (depending on the length of the vibrator head and other factors). The layers should be as level as possible so that the vibrator does not need to move the concrete laterally, since this will cause segregation. Fairly level surfaces should be obtained by depositing the concrete in the form at close intervals. Where there are some mounds or high spots in the surface of the concrete as placed, a vibrator should not be stuck into the center of each mound to knock it down. Hand or mechanical (screed) levelling is recommended.

After a level surface has been attained, the internal vibrator should be rapidly inserted vertically, at uniform spacing over the entire area of the placement, to the bottom of the layer, and at least 2 to 3 in. into the preceding layer (except for face mix) if there is such. The distance between vibrator insertions should generally be about 1½ times the radius of action, or such that the area visibly affected by the vibrator overlaps the adjacent just-vibrated area by a few inches. The vibrator should not be inserted within 2 ft. of any leading unconfined edge.

Vibrators shall not be allowed to contact forms for exposed concrete surfaces because contact may mar and disfigure the concrete surface. Internal vibrators should not be inserted closer to the form than about 2 in. or the coarse aggregate will be driven away from the form face producing local pockets of fine material (stinger marks) on the surface. Very high frequency, 14,500 to 18,500 vibrations per min., may decrease this problem. Care should be taken to avoid vibrating the reinforcement as this may cause ware and reinforcement.

The size (centrifugal force) and spacing of form vibrators should be such that the proper intensity of vibration is distributed evenly over the desired area of form and no form damage occurs. The spacing is a function of the type, stiffness and shape of the form, depth and thickness of the concrete, force output per vibrator, workability of the mix, and vibrating time. Present knowledge is inadequate to provide an exact solution to this complex problem.

Backup concrete compacted by form vibration should be deposited in layers, usually 6 to 12 in. thick, with each layer vibrated separately. Alternately, ribbons of concrete, 2 to 4 in. thick, should be continuously placed accompanied by continuous vibration. The latter procedure can produce surfaces nearly free of air voids. Vibration times are considerably longer than for internal vibration, frequently as much as 2 min.

Surface vibrators exert their effects at the top surface and consolidate the concrete from the top down with an effective depth of vibration of approximately 6 to 8 in., in addition to their leveling effect which assists in finishing. It is bad practice to try to get much compaction with surface vibrators because any violent action at the surface tends to cause segregation and create a layer of weak mortar.

Surface vibrators may be used to consolidate flat units or horizontal form beds or may be used to obtain a compacted and smooth top surface on units that have first been consolidated by other means. Care shall be exercised to prevent a smooth face mix surface which may result in poor bond of backup concrete.

Surface vibrators shall be moved at a rate so vibration is sufficient to embed the coarse aggregate and bring enough paste to the surface for finishing. The vibration and rate of movement shall be sufficient to compact the full depth of the layer. Solid plate vibrators should be operated at a slight angle.

A vibrating table or casting deck is best used for flat or low profile units, and is an easy and effective application of external vibration.

The choice of vibrators and their initial spacing should be based on the formulas given in Appendix D and previous experience. As in the case of form vibrators, it is advisable to check the frequency and amplitude at several points on the table, using a vibrograph or other suitable device. The actual acceleration may then be computed. The vibrators should be moved around until dead spots are eliminated and the most uniform vibration is attained.

5.5.5—Curing

Proper curing of fresh concrete by any method requires moisture be retained in order for complete hydration of cement to take place and to prevent formation of surface cracks due to rapid loss of water while the concrete is plastic; favorable temperatures and time are also necessary. Curing procedures shall be well established and properly controlled to develop the required concrete quality and minimize any appearance blemishes such as non-uniformity of color, staining or surface cracking.

In the manufacture of precast concrete, the initial curing of the concrete usually takes place in the form. Secondary curing takes place after the product is removed from the form.

To produce concrete of uniform appearance, every endeavor should be made to provide consistent and uniform curing conditions from day to day. In general, curing of precast units has received less emphasis than other quality control measures. However, this is justified for several reasons:

(1) Secondary curing may be less important in precast concrete because design strengths are established so that the precast units will resist maximum stresses which occur during stripping and handling. Generally, after in-plant casting and finishing, sufficient curing has taken place to elevate the compressive strength of the panels to at least 3500 psi. Most of this strength gain occurs during initial curing, generally at 20 hrs. or sooner. Consequently, the initial curing period is more crucial than subsequent curing.

(2) Mix proportions of precast concrete generally involve the use of high Type I cement contents or high-early-strength cement to assure adequate stripping and service compressive strength.

Curing after the first 16 to 20 hrs. is difficult to achieve because finishing and patching generally require interruption of curing. However, some finishing techniques, particularly those using water, contribute to the efficiency of the curing.

In practice, the primary curing in the mold is often the only form of curing used. Also, the various methods of secondary curing are sometimes not completely effective and may cause discoloration of the concrete surface resulting from variation in curing conditions or from staining.

The concrete in the mold shall be maintained at a temperature of not less than 50 F during the curing period. Curing shall be started immediately following initial set of the concrete. The time between placing of concrete and the start of curing is critical in drying and plastic shrinkage cracking.

Many plants use a 16 to 18 hrs. initial curing period. During this period positive action should be taken to provide heat (if necessary to maintain minimum temperatures) and to prevent loss of moisture from the unit. Curing materials or methods that permit one portion of an element to cure or not dry out as fast as other portions produce color variations in the finished product and differential shrinkage of the concrete which leads to warping of the precast element.

Actual temperature and duration of curing shall be such that the stripping strength indicated on the production drawings (usually a minimum of 1500 psi) has been reached before a product is removed from its form. The stripping strength shall be set by the plant, based on the characteristics of the product. It shall be high enough to ensure that the stripping does not have a deleterious effect on the performance or the appearance of the final product. The critical strength in the curing process becomes the strength at which the product may be safely handled. Prior to stripping or handling, the strength of the product shall be determined by test specimens cured in the same manner as the product or by other testing such as impact testing tools.

Concrete units after stripping must be kept in a surface-damp condition at a minimum temperature of 50 F until they reach 3500 psi or the strength established as the minimum for allowing exposure to local climatic conditions. When surface retarders are used, finishing shall be completed immediately after stripping and prior to additional curing. It may be necessary to interrupt the secondary curing to examine the surface finish and to accomplish any required patching. The curing may be interrupted provided that the period in which the element does not gain strength is not so extensive as to endanger completion of strength gain to final, specified level.

When precast units have reached a concrete strength of 3500 psi, it is usually safe to expose them to outside weather conditions provided further surface treatments will not be adversely affected. Except for special locations or climates with prolonged periods of below 50 F temperatures, curing in storage yards should enable the units to reach final design strength. The establishment of a strength level where exposure to local climatic conditions is considered safe by individual plant standards or local practices does not relieve the precast concrete manufacturer of his responsibility to prove that his products have reached the required final design strength.

In addition to regular test cylinders cured in accordance with normal ASTM requirements, for load bearing or segmental units extra test cylinders should be made and cured similarly to the precast units to verify curing results and determine the actual strength of precast units at time of shipping.

After removal of precast units to the storage yard, care should be taken to prevent rapid loss of moisture. Many areas experience a high ambient relative humidity throughout the year, and additional protection from rapid drying is not required. In other areas, hot, dry weather prevails, causing a rapid rate of drying of the concrete. Care should be taken to allow the units to dry slowly under these conditions. Concrete that has been allowed to dry quickly will be lighter in color initially than concrete that has been kept moist. This difference in color may persist although it will become less marked in time.

The actual curing of concrete depends on many variables including the mass of the member, type and properties of cement, air temperature, humidity and other variables. *Recommended Practice for Curing Concrete* (ACI 308–71) describes various curing procedures in detail.

5.5.6—Stripping

The stresses due to stripping depend on the shape of the element, the type of mold and release agent used. These stresses occur primarily as a result of the member being manufactured in an orientation different from that of its service life and the strength of the concrete at stripping being less than at any later time.

Most precast concrete units are cast in a flat position with the exterior face of the unit down. Depending on the weight of the unit and the location of the inserts, the unit may be stripped with or without an auxiliary spreader beam by means of overhead cranes or lift trucks. To minimize stresses during lifting of castings from the molds, the use of vacuum-suction lifting devices or tilt tables may be used.

Care should be exercised in removing the precast element from the form or mold to prevent damage to the unit from overstress or chipping. Stripping shall not be carried out until all removable inserts and fastenings have been removed and removable parts of the form are released or removed. Lifting equipment should be in good operating condition and properly secured to the unit. As a crane or hoist provides a means of applying a force in one direction only, operators must receive instructions on this principle; the instructions should include established signals to a crane or hoist operator using conventional signs.

the mold through the use of compressed air, hydraulic pressure or vibration.

5.5.7—Handling

All precast elements shall be handled in a position consistent with their shape and design and as specified by the Engineering Department. For most architectural concrete units, vertical handling should be the rule. In the handling of beams, it is imperative they be maintained in an upright position and picked up and supported at points near their ends unless approved erection drawings designate otherwise.

Care shall be exercised to maintain the required condition, quality and appearance of all elements until finally installed. Units shall be handled without structural damage, detrimental cracking, architectural impairment or permanent distortion. Precast concrete units shall be handled at all times without developing stresses for which they were not initially designed. Corners and edges of units should be protected to prevent chipping and spalling.

All means of fastening and rigging shall comply with the best safety practice. All lifting from threaded inserts shall be with appropriate swivel bolt hardware suitable for the insert unless such lifts are made axial with the inserts, such as by direct bolt fastening to lifting beams or frames. If inclined lifting lines are employed, the angle to the horizontal should not be less than 70 deg. unless specifically shown by the erection drawings. If slings are used, the unit should be marked so that the slings are placed at the proper location. Periodic checks shall be made to insure that the bolts being used in the handling inserts are of sufficient length to fully engage all threads plus extending about 1 in. beyond the coil threads, when coil inserts are used.

The number and location of pick-up points for handling of elements and details of pick-up devices shall be considered integral parts of the design of precast concrete elements and shall be shown on the erection drawings. Elements shall be handled only by means of approved devices at designated locations.

5.5.8—Yard Storage

Units temporarily stored within the plant or in the general storage area shall be supported at the blocking points designated on the erection drawings. Units should be stored in a vertical or near vertical position with two-point supports spaced approximately at the fifth points. If support is continuous across three or more points, the panel may bridge over one of the supports (because of differential support movement) and result in bowing and cracking. Units shall be stored with identification marks visible.

Often the manner of storing depends on how the panel is to be shipped and what limitations the panel's cross sections impose on handling. Where practical, the panel should be stored in the same manner in which it will be shipped.

Dunnage and storage racks, such as horses, A-frames, and vertical racks shall be well constructed, preferably of concrete, to minimize warping, bowing, chipping or cracking of the precast units due to improper support or unanticipated stresses.

Protective resilient material should be provided at points of bearing and contact. All blocking, packing, and protective materials shall be of a type that will not cause damage, staining, or objectional disfigurement of the elements. When setting one unit against a previous one, non-staining protective blocks should be placed immediately in line with the supports behind the first unit. Staggered or irregular blocking should be avoided. Units should be stacked against both sides of the supports to equalize loading and to avoid overturning. Care shall be taken to prevent surface staining and chipping or spalling of the edges and corners of the units.

Storage support frames shall be aligned to insure that the precast units are supported in a given plane to prevent warpage. When long panels are racked vertically, support should be provided at each end to ensure that panels do not distort or twist during a long period of storage. Proper storage shall also give consideration to the potentially harmful effects of alternating sun and shade on the precast units. Storage racks, which support elements at any stage, shall be clearly marked with their safe load capacity. Where necessary, storage equipment shall be protectively coated to avoid any discoloration or staining of the finished products.

Exposed (finished) surfaces should be carefully spaced using a molded plastic bubble spacer suitably positioned to minimize the contact area in order to prevent differential curing or drying of the surface which will produce permanent color variations. Stacking some units so air circulation and sunshine cannot reach the faces, leaving some units indoors, or having variations in curing technique, can very seriously affect the comparative color of the finished units for the project.

The precast units should be protected from soiling, staining, and all contact with earth, oil, grease, and tar; contact with smoke from engines and salamanders should be prevented. Any soiling or weathering of units, which would result in a pattern different from the normal weathering as finally installed, shall be avoided protection from such soiling or weathering. The need for protection will depend on the configuration of the units, the length of storage time, and local environmental conditions.

To prevent rust staining on finished surfaces, all exposed metal inserts, anchorages, and other hardware shall be coated with a rust preventive material. Projecting reinforcement shall be coated with cement paste applied by brush or gloved hand; the coating should be removed prior to embedding the reinforcement in concreted connections. Inserts and other embedded items shall be protected from penetration of water or snow during cold weather. A block of foam plastic should be inserted in pockets or recesses which could fill with water and freeze in order to avoid the ice expanding and cracking the unit.

Section 6—Concrete Finishes

5.6.1—General

Finishing techniques used may vary considerably from one part of North America to another, and between individual plants. Many plants have developed specific techniques supported by skilled operators or special facilities. The plant shall develop quality requirements for all architectural finishes prior to undertaking actual production of such finishes. Such requirements shall include samples and production procedures. A finishing process shall produce an acceptable uniform appearance without loss of required concrete qualities.

All finishes of precast concrete units shall be stated on erection drawings. Reference samples or mockup units should be available in the plant so that all concerned can be sure that standards of finish and exposure are being maintained.

Exposed aggregate surfaces may be accomplished by removing surrounding paste through chemical processes, such as using retarders and acids, or mechanically through abrasive blasting, grinding or bushhammering. Each method may influence the appearance of the concrete surface. Different degrees of exposure by any of these methods are:

Light exposure—where only the surface skin of cement and sand is removed just sufficient to expose the edges of the closest coarse aggregate.

Medium exposure—where a further removal of cement and sand has caused the coarse aggregate to visually appear approximately equal to the matrix in area.

Deep exposure—where cement and fine aggregate have been removed from the surface so that the coarse aggregate becomes the major surface feature.

The extent to which aggregates are exposed or "revealed" is largely determined by their size. Reveal should be no greater than one-third the average diameter of the coarse aggregate particles and not more than one-half the diameter of the smallest sized coarse aggregate.

Features shall be incorporated into units having more than one finish to ensure proper demarcation between the finishes involved. Bushhammering and sandblasting can be fairly easily stopped along specific lines, while other combinations of finishes demand demarcation features. An acid-etched finish should generally be used for the entire unit.

For interior finishes, exposed areas should have finishes which are realistic in relation to the exposure, production techniques, configuration of the precast units, and quality requirements. For interior surfaces which will receive insulation or finishes applied to the concrete panels later, the corresponding finish requirements shall be specified and shown on the erection drawings.

The back of precast panels (normally the face-up in the mold) may be given a screed, broom, float, trowel or stippled finish. Magnesium screeds and floats should be used with air-entrained or lightweight concrete to minimize surface tearing and pullouts.

To obtain a durable surface on unformed concrete, proper procedures must be carefully followed. Such surfaces shall be filled and struck off immediately after concrete placing and consolidation and then rough floated. The operations of screeding, floating, and first trowelling should be performed in such a manner that the concrete will be worked and manipulated as little as possible in obtaining the desired result. Over-manipulation brings excessive fines and water to the top which impairs the quality of the finished surface causing such undesirable effects as checking, crazing, and dusting.

Similarly, each step in the finishing operation, from the first floating to the final floating or trowelling, should be delayed as long as possible and still permit the desired grade and surface smoothness to be obtained. Free water is not as likely to appear and accumulate between finishing operations if proper mix proportions and consistency are used. However, if it does accumulate, it shall either be allowed to evaporate or, if excessive, it may be removed by blotting with mats, draining, or pulling off with a loop of hose, so the surface can lose its water sheen before the next finishing operation is performed. Under no circumstances shall any finishing tool be used in an area before accumulated water has ment be worked into the surface to dry such areas.

Prior to initial set of the concrete, a check should be made to insure that the floating or finishing operation did not result in high areas or ridges around plates or inserts cast into the unit.

All safety hazards for any finishing work shall be evaluated by the manufacturer and proper safety precautions established as plant procedures. Special safety precautions in connection with finishing operations include eye, respiratory and body protection.

Exposed aggregates can be brightened by washing with a 5 to 10 percent solution of hydrochloric acid, which removes the dull cement film remaining from some exposure techniques, especially washing and brushing. The acid solution should not materially affect the cement or aggregate. The acid normally is applied to a prewetted surface by brush or it can be sprayed. The surface is wetted to reduce acid penetration. Immediately after each washing with the acid solution, the precast units should be thoroughly rinsed with fresh, clean water, to completely remove all traces of the acid. Proper precautions should be taken to protect all exposed hardware metal. Acid washes may also damage galvanized reinforcement if less than the recommended cover is used.

Acid cleaning is best used after a 1- to 2-week delay to insure more complete hydration but often is done immediately after initial curing to reduce handling operations. The surface should have at least 3 or 4 days of curing. Acid washing too soon contributes to formation of white deposits on units with a gray cement matrix or with dark colored aggregates. The reaction of hydrochloric acid and portland cement results in the formation of a somewhat soluble silica gel that becomes insoluble in about 30 min. and extremely difficult to remove. The acid and brush must be kept clean. When acid is brushed on to the surface, the brush may build up a concentration of insoluble silica gel in the bucket that may then be picked up by the brush and smeared over the surface. Hydrofluoric acid is effective in removing deposits but is extremely dangerous for inexperienced personnel. Such cleaning is definitely not suggested for use by regular plant employees unless previously trained.

5.6.2—Smooth

A smooth off-the-form finish may be one of the most economical, but is not necessarily the easiest finish to accomplish uniformly. Many of the esthetic limitations of smooth concrete are masked by creating profiled surfaces (fluted, sculptured, board finishes, etc.), subdividing into smaller surface areas, or using white cement.

The cement exerts the primary color influence on a smooth finish because it coats the exposed concrete surface. The influence of the coarse aggregate is very minimal but that of the fine aggregate is of some importance. The smooth finish is particularly prone to color differences if only gray or buff cements are used.

When a glossy, ceramic-like finish is desired, plastic liners are normally used. Metal or highly polished wood produces a very smooth surface. Coated plywood produces a fairly smooth surface.

Smooth concrete may be susceptible to surface crazing when exposed to wetting and drying cycles. This is merely a surface phenomenon and does not affect structural properties or durability. In dirty atmospheres, crazing will be accentuated by dirt collecting in the tiny lines. This will appear more in white than gray finishes and more in horizontal than in vertical surfaces.

Smooth-finished units will normally have air voids on return surfaces. Retaining them rather than attempting to eliminate them by sack-rubbing may be preferable. Samples should be used to establish acceptability of such voids with respect to frequency, size and uniformity of distribution. For true economy, units with smooth surfaces should be produced without additional surface treatment after stripping. This, in turn, demands the following precautions:

(1) Attention to detailing with provisions for ample draft, proper edges and corners and suitable water drips and other weathering details.

(2) Well constructed molds, so that imperfections will not be mirrored in the unit. The use of plastic molds with a matte finish, which is smooth but not glossy, will help prevent crazing.

(3) Ensure mold release agent is same throughout production and is applied by same personnel under as nearly identical conditions as possible each time. (Some release agents help reduce the crazing tendency, probably by breaking the contact with glossy surface of the mold.)

(4) Concrete mix designs that combine a minimum cement content and a constant, low water-cement ratio with high density, in order to minimize crazing, entrapped air voids and color variations. The mix should be fully graded with aggregate fines below a No. 50 screen not in excess of 5 percent.

(5) Proper consolidation and curing to minimize uniformity shortcomings which show easily on such surfaces, particularly with gray concrete mixes. Uniform slow curing with minimum loss of moisture from the smooth surface will help minimize crazing tendencies.

(6) Efforts to minimize chipping or other damage because smooth finish patches require special skill to achieve a good match.

ing plant has the facilities to produce this high quality concrete mix and equipment for high energy consolidation. This, in turn, demands strong molds and secure fastening of reinforcing cages.

5.6.3—Retarded

Retardation involves the application of an agent to the concrete surface (normally the mold surface) that prevents the cement paste from hardening within a time period and to a depth depending upon the type or concentration of retarder used. Chemical retarders are available for the face-up or face-down methods of casting, and for vertical as well as horizontal surfaces. Retarders are also available for light, medium, heavy, and very heavy exposures. The function of the retarder is to delay, not kill, the set of the surface cement paste in order that the aggregate can be easily exposed.

Retarders are usually clear liquids with a dye added to facilitate even application. Dyes also are used for color codifying to indicate retarders of varying strengths (degrees of penetration). Drying times are variable and the faster a retarder dries the better its performance. Retarders possess various degrees of resistance to abrasion. This is important for built-in resistance to abrasion by the concrete during placing into forms coated with a retarder. Retarders are formulated so that the retarded matrix either remains on the concrete unit or stays on the forms. The choice depends on the particular operation under consideration. Some retarders are effective for long periods of time while others are active for only a few hours. The presence of an accelerator in concrete or the heating of concrete to accelerate strength gain will reduce the time during which the retarder is effective. This difficulty can generally be overcome by using a surface retarder with a concentration such that it would normally produce an etch deeper than that desired. Alternately, a specially formulated retarder, but one that has been thoroughly tested, can be used.

Surface retarders being considered for a project shall be thoroughly evaluated prior to production. A sample panel should be made to determine any adverse effects from the form or concrete materials. This involves using the particular type of cement, aggregate, and specific mix selected for the product. The effectiveness of retarders will vary when the heat of hydration of the cement is altered, either by larger concrete masses, use of insulation in sandwich panels, changes in temperature (ambient and concrete) and/or humidity, or by changing cements. Variations in the slump of the concrete also may affect the reactions of the retarder from unit to unit. The reveal or retardation will be deeper: (1) the wetter the mix; (2) the slower the time of set; (3) the more sand in the mix; and (4) the closer together the coarse aggregate.

When using retarders, the manufacturers' recommendations should be closely followed. Surface retarders can be applied by roller, brush or spray. Extreme care should be taken to insure uniform application of the retarders to the mold surface. Unless desired, care also shall be taken to avoid any one part of the mold inadvertently receiving a double coat of retarder since this would give local, deeper retardation. Over- or under-retarded areas will stand out prominently, especially on large surfaces. There is often a tendency to coat excessively around details in an attempt to obtain complete coverage. This practice can result in a local weakening of the final detail with the possibility that parts of the casting become dislodged at the time of demolding. Corners and bottoms of any grooves require removal of any excess that may have collected. A retarder applied only to a part of a form face may not be very successful because of the ragged effect produced at the edge of the treated area, unless a demarcation strip is used.

The retarder should dry before the concrete is placed to avoid scuffing. If forms are exposed to sunlight too long before placing, a retarder's action may be nullified and large under-retarded areas may result. The same may happen if water contacts mold surfaces treated with a retarder prior to placing concrete.

Since the most suitable finishing time may vary from 12 to 24 hrs. after casting, preliminary tests should be performed before planning the casting for a large contract. The timing of the surfacing operation must be consistent as most retarders cease to delay the hardening process when the panel is exposed to air and light. Variation in the time cycle varies the amount of effort required to achieve a uniform exposure. Whether the matrix is removed by water scrubbing or mechanical processes, it is recommended that the operation begin immediately after stripping before the matrix becomes excessively hard. Power brushes and sanders may burnish the aggregate or damage the surface and shall not be used without prior trials. Unformed surfaces may be treated at any time after initial set has taken place.

After the aggregate is properly exposed, and the panel is well cured, the exposed faces of the precast units and all edges where sealant material is to be applied may be given one or more washings with a 5 to 10 percent solution of muriatic acid to thoroughly clean the exposed aggregate and to remove any retarded cement paste and foreign materials. See Article 5.6.1 for a further discussion on acid cleaning.

Water washing is normally done to unformed surfaces or to retarded surfaces from which the molds are stripped prior to hardening of the cement.

The aggregate may be exposed by carefully washing the exposed surface with water while the unit is still in the form. The concrete should be sufficiently set to prevent overexposing or dislodging of the aggregate. The concrete should be allowed to stiffen until the water sheen disappears and the surface resists the imprint of fingers applied with the full body weight imposed upon them. At this time, which corresponds roughly to initial set of the concrete, the surface layer of mortar is carefully washed away by using a light spray of water and brushing until the desired exposure is achieved. Timing of this operation is critical since the environmental conditions have a considerable bearing on the time of set. The placing phase should be arranged so that large numbers of molds do not need to be washed at the same time. Ideally, the same person should wash all the units that are produced and reference must be made to an approved sample at all stages of production. The use of a water-soluble surface retarder uniformly sprayed over a carefully trowelled surface will enable the treatment to be postponed for a number of hours. The uniformity of exposure depends on spreading the retarder uniformly. High pressure water jets used in combination with air may be used to expose the aggregate on retarded surfaces.

Warm water should be used to spray the surface of a heated panel as the use of cold water could cause thermal cracking. Depth of exposure will vary with the size of the aggregate and hardness of the matrix. Several passes may be required before the proper exposure is obtained. The aggregate should have a uniform exposure at the end of each washing operation. Once a uniform exposure is obtained the washing can cease when the flush water is clear and there is no noticeable cement film on the aggregate.

Soft and hard nylon bristle brushes and special exposed aggregate flush brooms are available for this operation. Plastic bristle brushes are preferred because they will not soften in water. Wire brushes may be required occasionally for particularly stubborn areas. Care should be taken to remove any pieces of wire that become embedded in the surface to prevent future rust stains. Power brushes may burnish the aggregate or damage the surface and should be used only after experimentation on sample panels.

The appearance of aggregates in precast units subjected to retardation or water washing will not change from the natural appearance of these aggregates prior to incorporation in the concrete mix. These methods may be used for all three degrees of exposure, but are most commonly used for medium or deep exposure.

5.6.5—Sand or Abrasive Blasting

Generally, sand or abrasive blasting of surfaces is done when shallow aggregate exposure is desired. This process is suitable for exposure of either large or small aggregates.

Blasting will cause some etching of the face of the aggregate, and the softer aggregates will show this to a greater extent beyond a medium exposure. Etching of the aggregate surface is more noticeable on dark-colored aggregates which have a glossy surface texture. This will produce a muted or frosted effect which tends to lighten the color and subdue the luster of the aggregate. Depth of sandblasting should also be adjusted to suit the aggregate hardness. For example, soft aggregates might be eroded at the same rate as the mortar; exposed aggregates lose their sharp edges when blasted.

Since some aggregates change color after sandblasting, trials of different abrasive materials with sample panels are desirable to check the texture and color tone.

Uniformity of depth of exposure between panels and within panels is essential in abrasive blasting, as in all other exposed aggregate processes, and is a function of the skill and experience of the operator. Different shadings and to some extent, depth of color will vary with depth of exposure. The depth of exposure should be measured by a pipe bit gage.

Type and grading of abrasives determine the surface treatment and shall remain the same throughout the entire project. Materials used for blasting operations are washed silica sand, certain hard angular sands, aluminum carbide, blasting grit such as power plant boiler slag, carbonized hydrocarbon, crushed chat a waste material from lead mining, and various organic grits such as ground shells and corncobs.

Sands should be free of deleterious substances such as fine clay particles. If sand must be used as the abrasive, high silica sand should be used rather than bank or river sand. Silica sand does not break as readily, thus much less fine-sized dust is formed. Also, the abrasive used should not cause any color contamination. By using some types of colored abrasives it is possible to impart color to the surface of the concrete. With certain combinations of gradation, pressure and volume, impregnation of the abrasive in the surface can occur. If this proves to be the case, an abrasive of similar color to the matrix should be used. However, this can be minimized by a change in the volume of material, its gradation, and the pressure being applied.

by experimentation. The nozzle shall be externally attached to the hose by a fitting which will positively prevent accidental disengagement. To enable the operator to have complete control over his equipment, the nozzle shall be fitted with an automatic cutoff (dead man's handle). A support shall be provided on which the nozzle may be mounted when not in use.

In the application of dry or damp abrasive propelled by air, static electricity can accumulate on the operator's body. To control this problem, a properly grounded conductive hose should be used. The hose line should have adequate strength for the pressure being used. The inside diameter of the hose should be no less than 1½ in. or four to six times the diameter of the nozzle orifice to keep the sand in continuous suspension while traveling through the hose.

In abrasive blasting, the major dust hazard is from sandblasting. This is a serious hazard because sufficient silica dust breathed into the human lungs causes silicosis, which may cause total disablement. Only supplied-atmosphere (or air-fed) respiratory protective equipment approved by the Bureau of Mines shall be used. Dust-filter respirators shall not be used for continuous protection where silica sand is used as the abrasive. The air supply for abrasive-blasting respirators shall be free of harmful quantities of dusts, mists or noxious gases. Screens may have to be provided to protect the surrounding work and personnel from flying grit, and blasting should not be done in windy conditions.

If blasting is done in an enclosure it shall be ventilated in such a way that a continuous inward flow of air will be maintained at all openings of the enclosure during the blasting operation.

Dust and abrasives should not be allowed to accumulate in such a way as to create a slipping hazard.

Operators should be equipped with heavy gloves and aprons or equivalent protection to protect them from the impact of the abrasives.

5.6.6—Form Liners

Form liners may be incorporated in or attached to the surface of a form to produce the desired pattern, shape or texture in the surface of the finished precast concrete unit. A form texture can be of considerable influence in assisting as-cast surfaces to appear more uniform. Wood, steel, plastics and rubber materials are most commonly used as form liners. Regardless of the type of form liner used, draft must be considered to prevent chipping or spalling during stripping of the precast unit from the mold.

The method of attaching form liners should be studied for resulting visual effect. Liner panels shall be secured in forms by gluing or stapling, but not by methods which will permit impressions of nail heads, screw heads, rivets or the like to be imparted to the surface of the concrete, unless desired.

5.6.7—Tooled or Bushhammered

Mechanical spalling and chipping to produce an exposed aggregate texture can be accomplished with a variety of hand and power tools. The technique usually is called "bushhammering." Pneumatic or electric tools may be fitted with a bushhammer, comb chisel, crandall, or multiple pointed attachments. The type of tool will be determined by the surface effect desired. Hand tools are used for small areas, corners, and for restricted locations where a power tool cannot reach.

Basically, all methods of tooling concrete remove a layer of hardened concrete matrix while fracturing the aggregate at the surface. Surfaces attained can vary from the light "scaling" to a deep bold texture achieved by jack-hammering with a single pointed chisel.

Scaling is the lightest texture in bushhammered finishes. It is achieved by passing a triple-pronged scaler (originally developed to remove scale from steel prior to painting) singly or in gangs over the surface to remove only a thin skin. A single-head scaler is lightweight and can be readily manipulated by one man. No texture as such is brought out by this technique. Note that some aggregate is exposed and fractured in process. Under certain conditions almost the same result can be achieved by light abrasive blasting.

Although a dense, fully-graded mix is desirable, bushhammering has been successfully applied to gap-graded concrete. Natural gravels are inclined to shatter, leading to bond failure and loss of aggregate particles when bushhammered. Certain aggregates such as granite and quartz are difficult to bushhammer uniformly because they are very hard and may fracture into rather than across the concrete surface. Aggregates such as marble, calcite, and limestone are softer and more suitable for bushhammered surfaces. The comb chisel should be used only with the softer aggregates. Concrete containing soft aggregate cannot be satisfactorily point tooled.

To prevent loosening of the aggregate, a compressive strength of 4000 psi, and a minimum age of 14 days is recommended. In many cases, better uniformity may be obtained when the concrete is allowed to age for 21 days and the surface is dry. Exposing the aggregate by the use of metal tools is a procedure that requires trained operators in order to produce a uniformly textured surface.

Acid etching is most commonly used for light or medium exposure. In cases where aggregates are to be exposed to considerable depth, only acid resistive siliceous aggregates such as quartz and granite should be used. Carbonate aggregates e.g., limestones, dolomites and marbles, will discolor or dissolve due to their high calcium content. The aggregates on an acid-etched surface present a cleaner or "brighter" look. In normal weathering, the aggregates will lose this brightness and look very similar to their original condition.

Acid etching is a finish which is easy to produce in acceptable quality on a 12-in. sample, but one of the more difficult finishes to match with similar quality on large units.

Acid etching of concrete surfaces may result in a pleasing texture if the concrete mix and its consolidation has produced a uniform distribution of aggregates and cement paste at the exposed surfaces.

Any streaking of the cement, or variation in sand color or content may cause some uniformity problems, particularly when the acid etching is light or used for large, plain surfaces.

Acid etching may be accomplished by brushing the surface with a long handled stiff bristled fiber brush immersed previously in the acid solution or by immersing the unit in a tank containing from 5 to 35 percent hydrochloric acid. Only the first method should be used in the case of sandwich wall panels where the insulation goes to the edges of the panels and may be damaged by the acid.

The best results with acid etching of surfaces are obtained using low concentrations of solution after a 2-week delay, but often this finishing operation is done immediately after curing to reduce handling operations. The units to be treated should have uniform temperatures and strength levels (preferably about 4500 psi) when acid is applied.

Concrete should be well wetted with clean water prior to acid treatment because concrete is porous and acids will penetrate faster and deeper into dry concrete. The water fills the pores and capillaries and prevents the acid from etching too deeply. Older dried concretes are likely to be more carbonated. Although the reactions of carbonates with the acid might not be much faster than some other cement compounds, they cause greater effervescence so that the reaction is far more obvious and seems to be going faster.

Acid should not be allowed to lie on the surface for any length of time (15 min. is considered a maximum). Deep etch should be achieved by multiple treatment. Application of acid without vigorous brushing is relatively ineffective due to the formation of a silica gel which prevents further etching regardless of the amount of acid applied. This gel, a residue of acid and cement reaction, usually forms within 30 min. It can be readily removed by brushing during the reaction, but if allowed to remain in place, it may clog some of the pores. If a unit were dipped in a tank of acid, the same product would probably collect on the surface. Therefore, it would be desirable to devise a means of scrubbing it while it is immersed. After completion of acid etching, the unit must be thoroughly flushed with water. Neutralizers are sometimes recommended for use after application of acid to concrete. They are not needed as concrete should neutralize the acid as effectively as any neutralizer, and thorough washing should be adequate.

Prior to acid etching, all exposed metal surfaces, particularly galvanized metal, should be protected with acid-resistant coatings. These include vinyl chlorides, chlorinated rubber, styrene-butadiene, bituminous paints and enamels and polyester coatings. Acid washes may also damage the galvanizing or reinforcement if less than the recommended cover is used. If parts of the concrete surface are not to be acid etched they may be coated with an acrylic lacquer.

CAUTION: Hydrochloric (muriatic) acid is hazardous. Workmen performing this operation should wear protective clothing, breathing masks if used indoors, and rubber gloves, and should take necessary precautions to prevent contact of the acid with the skin. If the acid comes in contact with the skin, the affected area should be immediately flushed with large quantities of fresh water. Disposal and neutralizing of used acid must be carefully done to protect mechanical and electrical equipment from acid corrosion.

5.6.9—Honed or Polished

The grinding of concrete surfaces produces smooth, exposed aggregate surfaces. Grinding is also called honing and polishing depending on the degree of smoothness of the finish. In general, honed finishes are produced by using grinding tools varying from about No. 24 coarse grit to a very fine grit of about No. 300. Polishing usually is accomplished after honing and is done with an acid and polishing compound and a buffer. The honing and polishing of concrete are techniques which require highly skilled personnel.

Grinding elements may consist of carborundum particles bonded together with a resin, or diamonds set in a cutting surface. Diamond elements, initially more expensive, are used more widely because they cut much faster. Equipment may vary from a simple hand grinder to a very elaborate multihead machine.

ploying a finer grit than the preceding step. All voids in the concrete surface must be filled before each of the first few grinding operations using a sand-cement mixture that matches the matrix in the precast unit. Careful filling and curing are required and the next grinding operation must be delayed until the fill material has reached sufficient strength.

Compressive strength of concrete should be 5000 psi before starting any honing or polishing operations. If proper strength is not produced, grinding will cause dislodgement of aggregate particles and, if the concrete mortar is not hard, the surface will not grind evenly nor polish properly.

Since aggregates will polish better than matrix, it is essential to have a minimum matrix area. In choosing aggregates, special attention should be given to maximum size and hardness. The concrete should have a uniform and dense surface and aggregates should relate in hardness to the tooling. Softer aggregates such as marble or onyx are much easier to treat than either granite or quartz. This will be strongly reflected in the cost of such finishes. A combination of light acid-etching of the matrix area with polishing of the aggregates has produced excellent textures which weather particularly well.

5.6.10—Special Facing Materials

Finishes with materials other than normal concrete aggregates such as natural cut stone, brick, glass, structural tile, and architectural terra cotta (ceramic veneer), provide a great variety of textures for precast units. Quality requirements (design and production procedures) for these finishes shall be based on previous records with the identical materials, or sufficient testing of sample and mockup units to establish performance under the service conditions expected for the product. Particular attention should be paid to compatibility of materials with respect to expansion and contraction caused by temperature or humidity changes during the expected service conditions of the units. If materials do not have similar physical properties, the final design should include compensation for some interaction of the different materials.

Facing materials are dimensionally stable under a uniform temperature environment. The concrete, after its initial set, begins to shrink as it loses excess water to the surrounding environment. If they are bonded, the shrinkage of the concrete is restrained by the facing. The result is compressive stresses in the facing and tensile stresses in the concrete at the veneer-concrete interface. In a simple span, which is the case for most veneer precast panels, the deformation resulting from these stresses will cause an outward bowing of the veneer surface. The flat surfaces and straight arrises of cut stone reveal bowing far more prominently than in regular concrete panels. Therefore, bowing is a critical problem even though the rigidity of the cut stone helps to resist bowing.

Cracking in the veneer may occur if the bonding or anchoring details force the veneer pieces to follow the bowing. This is particularly critical where the face materials are large (cut stone) and the concrete shrinkage is significant. To control concrete shrinkage necessitates close attention to mix proportioning, continuing control of water and cement content in the mix, and prolonged curing under proper humidity conditions.

In the case of differential thermal expansion, the direction of deflection depends on the coefficients of expansion of both the facing and concrete. If the facing has a large coefficient of expansion, stresses in the panel (under decreasing temperature) will be the reverse of those due to shrinkage. For rising temperatures, the stresses and deformations will be added to that of shrinkage. The reverse situation exists for conditions where the coefficient of facing is less than that of the concrete. It is desirable, therefore, to utilize a backing concrete which has a minimum shrinkage coefficient and a thermal expansion coefficient that closely approximates that of the facing veneer.

Even with concrete shrinkage kept to the lowest practical level, there will still be some interaction with the facing material either through bond or the mechanical anchors of the facing units. However, this interaction will be kept to a minimum if consideration is given to a complete bond breaker between the face material and the concrete. Connection of the face material to the concrete should be with mechanical anchors which can accommodate some relative movement. This is, of course, a necessity if bond breakers are used. Materials for such inserts or ties should be such that catalytic or corrosive action will not occur.

The strength of the facing veneer material must be known or determined along with the anchor system to assure adequate strength to resist flexural stresses during handling, transportation and erection.

For cut stone finishes, emphasis on samples and mockup units is particularly important, and should be supplemented with actual tests on behavior of the unit for anticipated temperature changes. To the degree it is possible to test or judge from earlier performances, durability of the combined unit should be investigated.

Full scale mockup units with cut stone in actual production sizes, along with casting and curing of the units under realistic production conditions, are essential for each new or major application or configuration of the cut stones. Bowing should be carefully measdetails of stone sizes and fastening determined to suit the observed behavior.

Natural stone facings should be sized (length and width) to a tolerance of $+0$, $-\frac{1}{8}$ in. Tolerance allowance for out-of-square should be $\pm\frac{1}{16}$ in. Flatness tolerances for finished surfaces will vary depending on the type of finish. Tolerances vary from $\frac{3}{64}$ in. for polished surface to $\frac{3}{16}$ in. for flame cut (thermal) finish when measured with a 4-ft. straightedge. Thickness tolerances are not important except in the case of a corner butt joint. In such cases, the finished edges should be gaged to within $\frac{1}{16}$ in. of specified thickness.

Anchoring of the veneer to the concrete backing should be of such size and quantity as to secure the veneer by mechanical means without depending on any concrete bond. In the case of some limestone veneers, an epoxy bonding agent that will cure in the presence of moisture may be used.

Stone veneer should be supplied with holes predrilled in the back surface for attachment of mechanical anchors. Preformed anchors fabricated from stainless steel Type 304 should be used. The number and locations of anchors are scheduled based on the height, width, and thickness of the cut stone facing unit, and on the desired mechanical bond. Close supervision is needed during the insertion and setting of the anchors.

Where a bond breaker is desired between the veneer and the concrete to allow for independent movement, one of the following methods should be used: (1) a liquid bond breaker applied to the veneer back surface prior to placing of the reinforcement and concrete, (2) a 6-mil polyethylene sheet, or (3) a $\frac{1}{8}$-in. ethafoam pad.

Each piece of cut stone should be positioned exactly in the form. Some of the cut stones are very easily stained by oils and rust and require the forms to be lined with polyethylene sheets or other non-staining materials. Joint width between veneer joints within a precast element should be a minimum of $\frac{1}{4}$ in. Joints should be filled with sand, a non-staining spacing material or a resilient sealant backup material which will not stain the veneer or adversely affect the specified type of sealant to be applied to the joints later. The gasket shall be of such size and configuration as to provide a pocket to receive the sealant and also prevent any backing concrete from entering any portion of the joint between the veneer units. This material should be removed after the panel has been removed from the form (unless it is a resilient sealant backup).

Finished veneer units should be stored or shipped on their backs with the veneer facing up or on the concrete edge of the panel.

Clay products which are bonded directly to concrete include brick, structural facing tile and architectural terra cotta (ceramic veneer). Ceramic glaze units may craze from freeze-thaw cycles or the bond may fail on exposure. Therefore, where required for exterior use, the manufacturers should be consulted for suitable materials.

The nature of the surfaces of the brick are important for bond. Smooth, dense, heavily sanded or glazed surfaces are not usually satisfactory where high bond is required. Textures that may be specified to give increased bond include scored finish, in which the surface is grooved as it comes from the die; combed finish where the surface is altered by parallel scratches; and roughened finish produced by wire cutting or wire brushing to completely remove the smooth surface or "die skin" from the extrusion process. When die skin or heavily sanded brick must be used, a mechanical bond with corrosion-resistant metal ties should be used.

Brick with an initial rate of absorption (suction) less than 20 g per min. per 30 sq. in. when tested in accordance with ASTM C 67 are not required to be wetted. However, brick with high suction or with an initial rate of absorption in excess of 20 g per 30 sq. in. should be wetted to reduce the suction, and thereby improve bond, prior to placement of the concrete.

Brick-faced units should have joint widths controlled by locating the bricks in a suitable template set out accurately on the mold face. A fine sand may be placed between the bricks to provide a mild locking action to prevent movement of the individual units. After this, either a 1:4 cement-sand mortar backing can be placed or concrete carefully laid on the back of the bricks and the main concreting process carried out.

Architectural terra cotta (ceramic veneer) units should be soaked in water for at least one hour in order to reduce suction. They should be damp at the time of concrete placement. The backside of the terra cotta units should have dovetails in order to develop adequate bond to concrete.

Ceramic or mosaic surface can be achieved by placing the facing material in the form and applying a thin grout film over the entire surface which will fill the joints and act as bonding material between the facing and the fresh concrete placed on top of it. The bond between the facing and the concrete varies depending on the absorption of the ceramics or mosaics. Low absorption will result in poor bond, as will a high absorption due to the material sucking all the water from the interface and leaving a gap.

Glass mosaics need special attention to avoid alkali-aggregate reaction causing bond failure. They should be painted or sprayed with an epoxy resin and broadcast with fine sand while the resin is wet.

thus upset the finished surface.

After removal of the units from the mold the exposed surface should be cleaned by brushing with water.

5.6.11—Sand Embedment Method

When special facing materials, e.g., stones ranging from 1 to 8 in. in diameter or flagstones, are to be exposed, the sand embedment technique is frequently used.

One production method is to spread a layer of fine sand over the bottom of the form to a depth of about one-third the diameter of the uniform size facing aggregate used. Aggregate should be pushed together into the sand for dense coverage. Extreme care should be taken to distribute the aggregate evenly and densely. When all aggregate is in place, a fine spray of water should be used to settle the sand around the aggregates so that each piece is held securely. About one-third to one-half of each piece of aggregate should be embedded in the sand. Instead of sand, a gel-like surface retarder may be used. Aggregate should be embedded in retarder to one-half the desired exposure.

An alternate method is to spread a layer of the aggregate on the panel form and pack it closely. Fine, dry sand should then be sprinkled over the aggregate and allowed to sift down around the pieces until its depth is one-third to one-half the aggregate size. Excess sand on the rocks should be pushed down around the aggregates with a soft bristled brush and an air blast. The aggregate should be moistened with a fine spray of water to settle the sand firmly into place, and then a structural concrete backup cast to the desired thickness.

If a white matrix is desired, a white mortar, consisting of one part white air-entrained cement to 2½ parts well-graded white or light-colored sand with sufficient water to make a creamy mixture, should be placed over the aggregate.

The mortar mix or part of the backup concrete should be carefully placed on the aggregate with shovels and further spread with trowels to insure that it is worked around all of the individual pieces of aggregate. Then it should be screeded to a flat surface before the steel is placed. Care should be taken not to dislodge any of the aggregate when placing the first layer of mortar or concrete.

If a mortar facing mix is used, usually the backup mix should be of a low slump (a maximum of 1 in.), to absorb excess water from the facing mix. Otherwise, the backup mix should be standard structural concrete with a slump of 2 to 4 in. Care must be exercised during vibration not to disturb the sand or aggregates causing uneven aggregate distribution.

When the panels have cured they should be raised and any clinging sand removed by brushing, air blasting or washing with a stream of water. Some sand bonds to the concrete; therefore, the color of the bedding sand should be carefully chosen to harmonize with the aggregate to be exposed.

Where facing materials are of mixed colors, their distribution must be carefully observed and where very large stones are hand-placed, it is advisable to check for the formation of unintended patterns or local high incidence of a particular color.

If it is the intention when using some aggregates to expose a particular facet of the stone, placing should be checked with this in mind before the matrix is applied.

5.6.12—Face-up Method of Exposing Aggregate

When horizontally cast units require an exposed aggregate finish on both sides, the face-up and face-down methods are both used on the panel. Face-up methods usually involve embedding the coarse aggregate in the surface of the concrete by tamping or rolling. Then the aggregate is exposed by washing away the surface layer of mortar with water. Large aggregate can be hand placed in the matrix if one-third or less of the diameter of the individual pieces is left exposed. The face-up method is used widely for exposed surfaces with aggregates from ¾ to 1 in., though its use with larger aggregates in panels formerly cast face down on a sand bed is becoming more popular.

The backup concrete should be leveled below the top of the form a sufficient amount to allow for the top surface layer. Then a facing mix or matrix should be placed, vibrated and screeded, and, to ensure uniform aggregate distribution, aggregate of the same type and size as used in the facing mix should be seeded onto the fresh concrete. The screeding operation should produce a level surface ⅛ to 7/16 in. below the desired finish to allow for the volume of select aggregate to be seeded. About ⅛ in. should be allowed for aggregate sizes ⅜ to ⅝ in.; 3/16 in. for aggregate sizes ½ to ¾ in.; ¼ in. for aggregate sizes ¾ to 1 in.; 5/16 in. for aggregate sizes 1 to 1½ in., and 7/16 in. for aggregate sizes 1¼ to 2 in.

Aggregate to be exposed should be cleaned and wet thoroughly before use to prevent mixing water being drawn from the concrete. Wetting also serves to lubricate the entry of the aggregate into the surface of the facing mix. After wetting, however, the aggregate shall be drained to prevent free water being carried into the concrete.

Seeding should usually be started immediately after the base concrete has been placed, screeded, and darbied or bull-floated. The select aggregate should be carefully seeded by shovel or hand to of select aggregate required per square foot of surface may vary from about 3 lbs. for ⅜-in. aggregate to 6 lbs. for 2-in. material. Only one layer of stone should be added and stacked stone and flat or slivery particles removed. Handwork may be necessary at difficult locations including corners and along edges to ensure a uniform appearance.

Next, the aggregate should be embedded into the concrete by tamping with a wood float, a darby or the broad side of a piece of 2 x 4-in. lumber. Sometimes a rolling device such as a 4 or 5-in. diameter pipe can be used. The aggregate should be well tamped in the fresh concrete without lateral displacement. A magnesium float or darby should be used for final embedment of the aggregate until mortar completely surrounds and slightly covers all particles. Too much working of the surface with these tools may depress the one size coarse aggregate too far below the surface. Appearance should be similar to a normal slab after floating with all voids and imperfections removed.

After the water has disappeared from the surface, two methods of exposure may be used: (1) the concrete can be allowed to set and then the surface brushed and washed to expose the aggregate, or (2) a surface retarder may be applied so that the aggregate may be exposed at a later time. Care should be taken to obtain uniformity of retarder placement. The retarder method is particularly advantageous on large units or when small-sized aggregates are seeded.

DIVISION VI—TRANSPORTATION AND ERECTION

Section 1—Responsibility

6.1.1—Objectives

The placement of architectural precast concrete in the structure permits final judgment of the product by the general public and architects, engineers and customers unassociated with the project.

No matter how well all phases of design, production and inspection are done, it still requires competent workmen who are properly trained to load, deliver and erect precast concrete units to achieve a complete, satisfactory job. Methods of erection should be such as to avoid soiling, cracking, chipping, or damage to units. Minor chipping and spalling may be repaired at the jobsite after installation if this is done to the satisfaction of the Architect-Engineer.

6.1.2—Manufacturers' Responsibility

The function of a producer subsequent to manufacture of architectural precast concrete products is highly varied from plant to plant and job to job. Products may be accepted by the purchaser f.o.b. plant site, delivered to the jobsite, or erected complete in place. It is not the intention of this Manual to prescribe erection practices; however, it is recommended that precast producers, regardless of contractual obligations, maintain adequate contact with the process of transportation and erection of architectural precast units to insure their correct incorporation into the completed structure.

On projects for which the precast producer has responsibility for erection, the erection should be under the surveillance of a competent supervisor properly trained in all aspects of this work, including handling, storing, erecting, connecting and weather sealing, and in application of all appropriate safety measures. He shall establish delivery sequences and erection schedules acceptable to both the General Contractor and the manufacturer taking into account all relevant information with respect to access, production sequence and the procedures described in Articles 6.2.1 through 6.2.3.

On projects for which the precast producer does not have the responsibility for erection, it may be expedient to assign an observer to advise and report on erection methods.

Prior to start of erection and scheduling of delivery equipment, a field check of the project shall be made by the erector to ensure that foundations, walls and the structure generally are suitably constructed to accept the precast concrete units. This should include a field check of the work affecting his contract, including the cast-in-place connecting hardware, and a check on dimensional tolerances and the age and strength of the structure's supporting elements. The site should be inspected for truck and crane access and possible storage. The above checks by the precaster's personnel are not applicable if the General Contractor elects to erect the architectural precast concrete.

Any discrepancies between design dimensions and field dimensions which could adversely affect installation should either be corrected before erection, or allowed for by some accepted method during the erection stage.

Section 2—Procedures

6.2.1—Handling

Handling of precast concrete units should be kept to a minimum. All precast units shall be handled in a position consistent with their shape and design to avoid excessive stresses and as shown on the approved erection drawings. Units shall be handled only by approved devices at designated locations.

In handling beams, it is imperative they be maintained in an upright position and picked up and supported at points near their ends unless approved erection drawings designate otherwise.

During handling, the units should not be subjected to undue stresses (limit stresses to values compatible with the strength of the concrete) caused by vibration, impact or lateral forces.

All means of fastening and rigging shall comply with OSHA safety practices. Proper attention to safety and prevention of damage to units is a prime consideration in all operations.

6.2.2—Loading and Delivery

The units shall be selected from storage, loaded and delivered in the proper order to meet the predetermined erection sequence.

Units shall be loaded and delivered as necessary:

(1) To permit their removal or erection from the load in proper sequence to minimize handling and hazards.
(2) With proper supports, blocking, cushioning, and tie-downs to prevent or minimize in-transit damage.
(3) With proper padding between concrete and tie-chains or cables to avoid chipping of concrete.
(4) To meet highway, railroad, or barge regulations.
(5) To permit their safe transportation.

The blocking points and orientation of units on the shipping equipment shall be as shown on the erection drawings.

A two-point support system with supports at fifth points should be used for panels shipped in a vertical or horizontal position. Alternative support methods may be necessary when panel configuration makes the two-point system impractical. Most panels should be loaded in vertical or near vertical position, supported on A-frames, when thickness to length ratio is greater than 1/50. Prestressed units may exceed this ratio without problems.

For long slender units, any noticeable indication of lateral deflection or vibration during transportation shall be corrected by rigid bracing between units or by lateral trussing. In extreme cases, provisions of strongbacks, stiffening trusses or frames may be required.

All blocking, packing and protective materials shall be of a type that will not cause damage, staining or other disfigurement of the units.

The erection supervisor must coordinate the arrival of the units at the jobsite and provide for possible storage and for erection in a safe manner within the agreed schedule and limits of available access, equipment, and with due consideration of other trades.

All precast concrete units shall be delivered to the site clearly marked as indicated on the erection drawings, showing date of production and an identifying mark that indicates the final position of the particular unit in the structure. Alternatively, a list showing this information and tied in with identification marks for individual units shall be supplied. Any members which require a sequential erection should be so marked so as to avoid errors. Weight of the unit should also be marked on the unit or otherwise communicated to transport and erection personnel, especially if the precaster does not erect the units himself. Marks should be located on an unexposed face of the unit (if possible) in the completed structure.

If possible, units should be unloaded by handling in a vertical position. All chains, binders, and banding should be removed from around the units. All bracing, packing, etc. and protecting edges of the panels should be carefully removed. If belts are used in unloading, only one unit at a time should be removed from the truck or car, and protective materials must be used between belts and point of contact with units. Gangs of units should not be removed with one lifting unless palletized.

Units should be lifted slowly from the transport vehicle. All blocking between the units should be free from the unit adjacent to it. If any binding occurs, the unit should be lowered and the obstacle holding the unit removed. Remaining adjacent units on the trailer should be tied or blocked to prevent tipping. The exterior unit should always be unloaded first from a stack to prevent of a stack. Balance of the trailer should be maintained by unloading alternate sides of the vehicle.

Required rotation of units should be done in the air and not accomplished by turning the units on the truck or ground, unless the unit is properly designed to resist such handling without any structural damage or chipping of edges and corners.

If the units are to be erected from the truck, the lifting devices should be bolted securely to the outside unit. The bolts should extend to the bottom of the attachment holes in the unit or at least 1½ bolt diameters in order to prevent unwinding or stripping of threads. Caution should be exercised to avoid bolts of improper length. Bolts too long, requiring extensive shimming may bend and fail. A minimum of two connections should be used when the panel will be lifted a distance beyond hand control so that the panel or the lifting line cannot spin and unscrew causing a disconnection and resulting fall of the unit.

If temporary job storage of units is required, the recommendations of Article 5.5.8 should be followed. In addition, site conditions, season of the year, and length of storage at the jobsite should be considered in determining the necessity of protection to prevent accumulation of dust, dirt or other staining material from discoloring the units.

6.2.3—Erection

Prior to erection of precast units, the jobsite should be checked for truck and crane access. If erection is to take place in a congested or constricted area, scheduling and coordination with other trades must be worked out. The locations of all connections integral with the building frame or foundation should also be verified as to position and elevation before any precast units are erected.

The precast erector should perform a survey of the building as constructed, and set out joint locations prior to actual product installations. This will keep the differential variation in joint width to a minimum, as well as identifying problems caused by building frame columns or beams being out of dimension or alignment. For multistory buildings, this joint layout check should be made every third or fourth floor.

The units shall be erected in sequence if indicated on the production or erection drawings, or as predetermined at the site, taking into account, at all stages, the actual loading on the structure, the loading on previously erected units, the connections, weather sealing and tolerances.

All precast concrete units shall be erected level, plumb, square and true within the allowable tolerances (see Article 6.2.4). They must be positioned so that cumulative dimensional errors do not exceed allowable tolerances. Horizontal and vertical joints shall be correctly aligned and uniform joint width shall be maintained as erection progresses. Units shall not be forced into place or installed by any method which would induce or impose any undue stress or overloads on the structure, on the units, or on the connections.

Temporary connections, bracing and guy wires must be fully secured to take the necessary loads including horizontal erection loads before the crane can release the element and before the components are fully assembled. Shores and braces should be maintained until proper alignment and adequate permanent support have been provided. Shoring and bracing should be installed as detailed on the approved erection drawings or as approved by a qualified designer. Each unit should be braced independently so that any one may be taken out without removing support from the remaining panels. No unit shall be left in a temporary or unsafe position without bracing at any time. The erector shall see that adequate barricades, warning lights and signs to safeguard traffic and people in the immediate area of all hoisting and handling operations have been provided.

Each precast unit should be securely fastened in place as indicated on erection drawings. Field checks are necessary to ensure that connections allow for free movement due to temperature expansion and contraction.

Where necessary, the erector should correct misalignment of units resulting from normal deflection and rotation of the supporting structure due to dead load of the precast units. Units may be erected with a predetermined allowance for such movements or, following installation, adjustments may be made to connections which are specifically designed for such movement. Adjustments or changes in connections which could induce additional stresses in the unit or connection assembly should be reviewed and approved by the Architect-Engineer.

Where welded connections are required, welding shall be performed by certified welders in accordance with the erection drawings which shall clearly specify type, extent, sequence if critical, and location of welds. Welding shall be in accordance with AWS D1.1. All work and materials of other trades in the area of welding shall be protected at all times.

Surfaces to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease or other foreign material that will prevent proper welding or produce objectional fumes. When making field-welded connections, the welding should be done in the down-hand position whenever possible.

desirable behavior may result. Welding should be avoided in confined places and where hardware is galvanized. If galvanized material must be welded, all weld areas shall be given a coat of zinc-rich paint immediately after welding and slagging.

With welded connections, units may be shimmed while initial tack welding is accomplished. Provisions must be made to hold the unit safely in place while adjacent units are being placed and final adjustments are made. Before temporary supports are released, the full weld should be in place at every connection of the precast unit.

When welding or burning with a welding electrode, the ground should be attached directly to the base metal. Under no circumstances should the member be used as a conductor for the ground as internal arcing on principal reinforcement may occur.

When welding in cold temperatures, preheating is required or special welding techniques such as thermite welding should be used. Moreover, welding in cold temperatures should be done carefully to prevent spalling of the adjacent concrete.

A fire extinguisher, of 5 BC type or higher and in operating condition, shall be located within reach of all burning and welding operations at all times.

Bolting shall be in accordance with erection drawings using materials specified by the Architect-Engineer. Clip angles should have a slotted hole at least 2½ in. long to allow for adjustments. Particular care should be taken to prevent damage to units when adjustments are being made to bring the unit into final position. When attachment is to be made with bolts, the depth of the hole in the unit shall be checked. A periodic check should be made to verify that all bolts are of proper length, thread and diameter.

Following erection of a precast unit, where slotted connections are used, a check of bolt tightness should be made. The bolt must be tight, but should not be so tight that it can not move within the connection angle slot. Washers may be required to assure that tension has been developed in the bolt.

At the end of each working day, all necessary measures shall be taken to protect the installation from damage. For example, where precast units in partially completed buildings could be damaged by weather, such as by freezing of water in holes and inserts, adequate temporary protection shall be provided.

As erection of the exposed precast work progresses, all mortar, plaster, grout, and other construction droppings should be removed by brushing or water washing. After final erection of precast work to acceptable alignment and appearance, including all connections and joints, the General Contractor should assume responsibility for protection of the work. The General Contractor should provide and maintain temporary protection to prevent damage or staining of units during construction operations after installation. Any cleaning or repair of precast concrete work subsequent to acceptance should be done by the erector or precaster, but under the responsibility of the General Contractor. See Article 6.2.6 for cleaning procedure.

The erector shall protect the unit and adjacent material such as glass and aluminum from damage by field welding or torch cutting operations and provide non-combustible shields (asbestos sheets) as necessary during these operations. To minimize staining, all loose slag and debris should be removed immediately after the welding is complete. All welds and exposed or accessible steel anchorage devices should be touched up with a rust inhibitive primer or, in cases of galvanized plates, a cold galvanized coating containing 95 percent zinc applied immediately after cutting or welding and slagging.

6.2.4—Tolerances for Erection

Erection tolerances are those required for realistic matching with the building structure, and will normally involve the General Contractor and/or different subcontractors such as precast erector. The basis for erection tolerances are determined by the characteristics of the building structure and site conditions and are directed to achieve uniform joint and plane wall conditions. They should be determined on the basis of individual unit design, shape, thickness, composition of materials, and overall scale of the unit in relation to the building. The specified erection tolerances affect the work of several trades and must be consistent with the tolerances as specified for those trades.

Final erection tolerances should be verified and agreed on before erection commences and, if different from those originally planned, stated in writing or noted on erection drawings.

Appropriate field procedures should be followed to ensure accurate application of tolerances. The General Contractor is expected, and should be required, to establish and maintain control points and bench marks in an undisturbed condition until final completion and acceptance of a project. Erection tolerances are less critical in structures consisting entirely of precast concrete units than for cast-in-place concrete or steel frame structures. Where precast units connect to site work, such as footings or foundation walls, ample erection tolerances are still required. The precaster should normally be allowed to suggest his own tolerances for the erection of precast concrete framing members.

Non-cumulative tolerances for the location of flat and vertical ribbed wall precast units are as follows:

Joint taper (panel edges not parallel)	1/40 in. per ft. length with a maximum of 1/4 in.
Step in face (see Fig. 6)	1/4 in.
Jog in alignment of edge (see Fig. 7)	1/4 in.

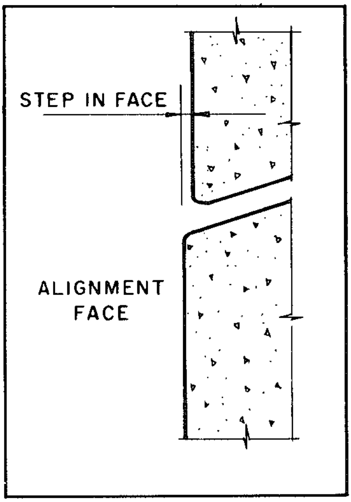


Fig. 6. Section showing step in panel faces

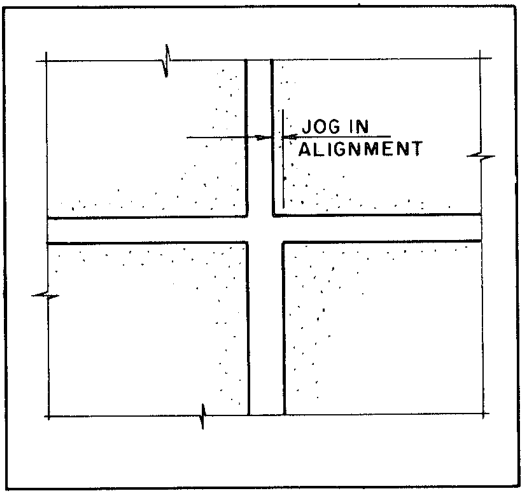


Fig. 7. Elevation showing jog in alignment of panel edges

6.2.5—Inspection and Acceptance

All chipping, blemishes or other damage occurring at the site shall be reported to the erection supervisor. He shall arrange for properly trained craftsmen to repair such damage, as outlined in Article 2.4.2, to provide a finished product of a quality no less than originally specified.

Immediately after erection, the erection supervisor should make a thorough inspection of the precast concrete installation and arrange for final repairs, cleaning where needed, jointing, readiness for other trades such as window installation, glazing, etc., and arrange for acceptance by the Architect. Factors affecting architectural precast concrete acceptability are discussed in Articles 2.3.1 and 2.3.2.

6.2.6—Cleaning

All exposed facing shall be cleaned as necessary to remove dirt and stains which may be on the panels after erection. The precast units shall be cleaned only after all installation procedures, including joint treatment, are completed.

It is recommended that the precaster and/or erector assist where possible in the final cleaning by checking the cleaner's operations, prior to actual execution, to ensure that no permanent damage to the precast work or adjacent materials is likely to occur.

If at all possible, cleaning of concrete should be done when the temperature and humidity are compatible to allow rapid drying. Long drying periods increase the possibility of efflorescence and discoloration.

A small area should be cleaned and appraised to be certain there is no adverse effect before proceeding with the work. A suggested order for testing appropriate cleaning procedures for removal of dirt, stains and efflorescence is:

(1) Dry scrubbing with a stiff fiber brush.

(2) Wetting the surface down and vigorous scrubbing of the finish with a stiff fiber brush followed by additional washing of the surface. Steam cleaning may also be tried.

(3) Chemical cleaning compounds such as detergents, muriatic acid or other commercial cleaners may be used in accordance with the manufacturer's recommendations.

If possible, a technical representative of the cleaning compound manufacturer should be present for the initial test application to assure its proper use. Consideration should be given to the chemical's effect on the concrete surface finish and adjacent materials.

Rubber gloves, glasses and other protective clothing should be worn by workmen using an acid solution. All precautions on labels should be observed because muriatic acid can affect eyes, skin, and breathing.

(4) Sandblasting may be used if this method was used originally in exposing the surface of the unit.

(5) For information on removing specific stains from concrete, reference should be made to *Removing Stains from Concrete,* published by the Portland Cement Association.

6.2.7—Clear Surface Coatings

Sealers or clear coatings may be considered for the possible improvement of weathering characteristics. They should not be used unless they serve a specific purpose.

Sealers may be applied for the following reasons:

(1) The prime justification for their use will appear as a potential improvement of weathering qualities in urban or industrial areas to reduce attack of the concrete surface by airborne industrial chemicals.

(3) To prevent change in appearance, particularly darkening of surfaces that are wetted, by making them water repellent.

(4) To reduce efflorescence, particularly with a gray or buff cement matrix. The use of a concrete sealer will prevent the absorption of additional moisture into the surface thereby minimizing or eliminating the migration of water to the surface.

(5) To reduce the incidence of lime leaching which may etch glass, aluminum and other lime susceptible construction materials.

(6) To reduce the tendency of soiling in the yard, in transportation, and on the building. Special sealers (often with short-term effect) which will not change concrete appearance, are used by some precasters to protect concrete during yard storage, particularly where dirty atmospheric conditions exist.

(7) To brighten aggregates and develop color tones that would otherwise be hidden.

A careful evaluation should be made before deciding on the type of sealers. Suggested sealers should be tested on reasonably sized samples of varying age, and their performance verified over a suitable period of exposure or usage based on prior experience under similar exposure conditions. Sealers should be applied in accordance with each manufacturer's written recommendations. Any coating used should be guaranteed by the supplier or applicator of the sealer not to stain, soil, darken or discolor the finish.

Surface coatings shall not be applied until all cleaning has been completed. In cases where the panels have been coated at the manufacturing plant and additional cleaning is required, it may be necessary to recoat those particular panels.

APPENDIX A

Considerations for the Architect-Engineer in Preparing Plans and Specifications

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* These articles also included in Appendix D.

APPENDIX B

Reference Literature

To comply with recommendations given in this Manual and to maintain contact with improvements in practice, it is essential architectural precast concrete plants be furnished with current reference literature and supervisory personnel be encouraged to make appropriate use of it. An adequate file of references should include applicable and current publications of the American Society for Testing and Materials; the American Concrete Institute; the Prestressed Concrete Institute; the Portland Cement Association; and similar agencies having pertinent applicable specifications dealing with manufacture of precast concrete. The following publications are recommended but no listing can be all inclusive.

American Society for Testing and Materials

The ASTM Book of Standards contains specifications and methods of tests for most of the materials of accepted standard practice used in architectural precast concrete. They also contain specifications and methods of tests for related materials. Subscribers to these publications receive notice of supplemental and revised specifications and specifications for new and related materials as they are developed.

The individual standards in these volumes which can be ordered separately are referred to in this Manual:

ASTM Designation	Title
A 27	Specification for Mild- to Medium-Strength Carbon-Steel Castings for General Application
A 36	Specification for Structural Steel
A 47	Specification for Malleable Iron Castings
A 82	Specification for Cold-Drawn Steel Wire for Concrete Reinforcement
A 123	Specification for Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars, and Strip
A 153	Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A 165	Specification for Electrodeposited Coatings of Cadmium on Steel
A 184	Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185	Specification for Welded Steel Wire Fabric for Concrete Reinforcement

	ity
A 307	Specification for Carbon Steel Externally and Internally Threaded Standard Fasteners
A 325	Specification for High-Strength Bolts for Structural Steel Joints, Including Suitable Nuts and Plain Hardened Washers
A 416	Specification for Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete
A 421	Specification for Uncoated Stress-Relieved Wire for Prestressed Concrete
A 490	Specification for Quenched and Tempered Alloy Steel Bolts for Structural Steel Joints
A 496	Specification for Deformed Steel Wire for Concrete Reinforcement
A 497	Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement
A 615	Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 616	Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
A 617	Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
A 666	Specification for Austenitic Stainless Steel, Sheet, Strip, Plate, and Flat Bar for Structural Applications
A 675	Specification for Special Quality Hot-Rolled Carbon Steel Bars Subject to Mechanical Property Requirements
A 706	Specification for Low Alloy Steel Deformed Bars for Concrete Reinforcement
A 722	Specification for Uncoated High-Strength Steel Bar for Prestressing Concrete
C 31	Method of Making and Curing Concrete Test Specimens in the Field
C 33	Specification for Concrete Aggregates
C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 40	Test Method for Organic Impurities in Sands for Concrete
C 42	Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 67	Sampling and Testing Brick and Structural Clay Tile
C 88	Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C 109	Test Method for Compressive Strength of Hydraulic

	Cement Mortars (Using 2-in. or 50-mm Cube Specimens)
C 117	Test Method for Materials Finer than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing
C 127	Test Method for Specific Gravity and Absorption of Coarse Aggregate
C 128	Test Method for Specific Gravity and Absorption of Fine Aggregate
C 131	Test Method for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine
C 136	Test Method for Sieve or Screen Analysis of Fine and Coarse Aggregates
C 138	Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 143	Test Method for Slump of Portland Cement Concrete
C 144	Specification for Aggregate for Masonry Mortar
C 150	Specification for Portland Cement
C 171	Specification for Sheet Materials for Curing Concrete
C 172	Method of Sampling Fresh Concrete
C 173	Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C 185	Test Method for Air Content of Hydraulic Cement Mortar
C 192	Method of Making and Curing Concrete Test Specimens in the Laboratory
C 227	Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
C 231	Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 260	Specification for Air-Entraining Admixtures for Concrete
C 289	Test Method for Potential Reactivity of Aggregates (Chemical Method)
C 295	Recommended Practice for Petrographic Examination of Aggregates for Concrete
C 309	Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C 330	Specification for Lightweight Aggregates for Structural Concrete
C 457	Recommended Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete
C 469	Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C 470	Specification for Molds for Forming Concrete Test

C 535	Test Method for Resistance to Abrasion of Large Size Coarse Aggregate by Use of the Los Angeles Machine
C 566	Test Method for Total Moisture Content of Aggregate by Drying
C 567	Test Method for Unit Weight of Structural Lightweight Concrete
C 586	Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)
C 595	Specification for Blended Hydraulic Cements
C 617	Method of Capping Cylindrical Concrete Specimens
C 618	Specification for Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete
C 666	Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C 805	Test Method for Rebound Number of Hardened Concrete
E 11	Specification for Wire-Cloth Sieves for Testing Purposes
E 329	Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction

For all materials and equipment used in the manufacture of architectural precast concrete, for which an appropriate ASTM designation has not been developed, manufacturer's specifications and directions should be available. Such materials and equipment should be used only when they have been shown by tests to be adequate for the purpose intended and their usage has been approved by responsible personnel of the Prestressed Concrete Institute.

American Concrete Institute

(1) Manual of Concrete Inspection
(2) Manual of Concrete Practice
  Part 1—Materials and Properties of Concrete
    Construction Practices
    Pavements and Slabs
  Part 2—Structural Design
    Structural Specifications
    Structural Analysis
  Part 3—Products and Processes

These volumes contain accepted ACI Standards, including the Building Code Requirements and appropriate publications covering all aspects of concrete proportioning, batching, mixing, placing and curing. They should be available in all architectural precast concrete plants. Some of the more pertinent recommended practices and guides are as follows:

ACI 211.1—Recommended Practice for Selecting Proportions for Normal and Heavy Weight Concrete
ACI 211.2—Recommended Practice for Selecting Proportions for Structural Lightweight Concrete
ACI 211.3—Recommended Practice for Selecting Proportions for No-Slump Concrete
ACI 212—Guide for Use of Admixtures in Concrete
ACI 213—Guide for Structural Lightweight Aggregate Concrete
ACI 304—Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete
ACI 305—Recommended Practice for Hot Weather Concreting
ACI 306—Recommended Practice for Cold Weather Concreting
ACI 308—Recommended Practice for Curing Concrete
ACI 309—Recommended Practice for Consolidation of Concrete
ACI 318—Building Code Requirements for Reinforced Concrete

Prestressed Concrete Institute

MNL-122—PCI Architectural Precast Concrete
MNL-116—Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products
MNL-119—PCI Architectural Precast Concrete Drafting Handbook
SLP-100—PCI Safety and Loss Prevention Manual

Portland Cement Association

EB1—Design and Control of Concrete Mixtures
IS142—Removing Stains from Concrete

U.S. Bureau of Reclamation

Concrete Manual

American Welding Society

AWS Designation	Title
A 5.1	Specification for Mild Steel Covered Arc Welding Electrodes
A 5.5	Specification for Low-Alloy Steel Covered Arc Welding Electrodes
D1.1	Structural Welding Code
D12.1	Reinforcing Steel Welding Code

APPENDIX C

Sample Records

The following suggested sample record forms include most of the information necessary for proper evaluation of quality architectural precast concrete. The reports serve as a permanent record of the manufacturing process in case this information is required at some future date.

Items that can be measured quantitatively are to be recorded in numerical terms. Items that must be evaluated subjectively should be rated A—B—C—D. A and B imply approval, C means marginal and D defines an unsatisfactory condition. Items such as length and width measurements can be given a check mark or "O.K." if they are close enough to the design dimensions to be within the tolerances listed in Article 2.3.1.

Where extra attention is required to improve material or product quality, or improve workmen quality performance, or to identify matters beyond the control of the workmen, remarks or sketches should be used. Remarks can be made on the back of the forms when there is not room on the front side.

PRECAST
CONCRETE INC.

QUALITY CONTROL

AGGREGATE GRADATION
ORGANIC IMPURITIES
MATERIAL FINER THAN 200
MOISTURE TEST

________ ________
Date Inspector

MATERIALS
CONTROL

SHEET NO: ________

AGGREGATES

Applicable Spec. ________ FINE AGGREGATE Date Del. ________

Sieve Size	Weight Retained (g)	% Retained	Cum. % Retained	% Passing	Specifications		Remarks
					ASTM C33		Bin ________ Tons Rep. ________
3/8"					100		
No. 4					95-100		
No. 8					80-100		
No. 16					50-85		
No. 30					25-60		
No. 50					10-30		
No. 100					2-10		
Pan							
		F.M.					

Applicable Spec. ________ COARSE AGGREGATE Date Del. ________

Sieve Size	Weight Retained (g)	% Retained	Cum. % Retained	% Passing	Specifications		Remarks
					ASTM C33		Bin ________ Tons Rep. ________
1"					95-100		
3/4"							
1/2"					25-60		
3/8"							
No. 4					0-10		
No. 8					0-5		
No. 16							

MATERIAL FINER THAN 200 SIEVE (ASTM C117)

________ Coarse Agg. ________ Fine Agg.

Supplier ________

Date Del. ________

Original Wt. of Sample ________ (at least 2.5 kg)

Dry Wt. of Orig. Sample ________ = B

Dry Wt. Sample After Washing ________ = C

A (% Material Finer than 200 Sieve) $= \frac{B-C}{B} \times 100 =$ ________

AGGREGATE MOISTURE CONTENT (C566)

Wt. Sample & Container (Wet) ________ (D)
Wt. Sample & Container (Dry) ________ (E) ________
Wt. of Container ________ (F)
Wt. of Moisture (D−E) ________ (G)
Net Dry Wt. of Sample (E−F) ________ (H)
% Moisture $= \frac{G}{H} \times 100 =$ ________

Speedy Moisture Test: ________ %

ORGANIC IMPURITIES IN SAND (C40)

Circle Color of Sodium Hydroxide Solution

Organic Plate No.
1 (desired)
2
3 (standard)
4
5

____
Supplier

____
Date Del.

PRECAST
CONCRETE INC.

QUALITY CONTROL

CONCRETE TEST REPORTS

Job ____________ Job No. ____________

Date ____________ Inspector ____________

MATERIALS CONTROL

SHEET NO: ________

ALL PRODUCTS

Mark No.	**Pour No.**	**Specimen No.**	**Slump (in.)**	**Air (%)**	**Unit Wt. (pcf)**	**Conc. Temp. °F**	**Amb. Temp. °F**	**Temp. Time**	**Date At Break**	**Time At Break**	**Curing Duration (hrs.)**	**Cylinder or Cube Strength (psi)**	**Design Strength (psi)**	**Remarks**

FACE MIX Mix Designation (sample number) ____________

BACKING MIX Mix Designation (sample number) ____________

Impact Hammer

Average Rebound Reading (R)	Compressive Strength (psi)

COMMENTS: ____________

____

____

____

____

____

CONCRETE YIELD COMPUTATION

Cement ________

Fine Aggregate ________

Coarse Aggregate ________

Admixture ________

Admixture ________

Water No. Gals. ________ x 8.33 ________

Total Wt. per Cu. Yd. (A) ________

Wt. Container & Concrete ________

Wt. Container ________

Wt. Concrete ________

Slump ________

Entrained Air ________

Container Size ________ cu. ft.

Wt. per Cu. Ft. (B) ________

$\text{Yield} = \frac{A}{B} =$ ________

AIR MEASUREMENT (ASTM C231)

Aggregate Correction Factor (G)

$h_1 =$ ________

$h_2 =$ ________

$G = h_1 - h_2 =$ ________

Apparent Concrete Air Content (A_1)

$h_1 =$ ________

$h_2 =$ ________

$A_1 = h_1 - h_2 =$ ________

A (Air Content) = $A_1 - G =$ ________

CONCRETE INC.

QUALITY CONTROL

BUILDING PRODUCTS

FORM SET-UP, CASTING AND
FINISHED PRODUCT

Date ____________________ Inspector ____________________

Mold No.: ____________

Job No.: ____________

Product: ____________

Form Oil: ____________

ID.	Job No.					
	Member Mark No.					
SET-UP DETAILS	Form Conditions & Cleanliness					
	Seams Sealed					
	Retarders					
	Design Length (Height)					
	Form Set-Up Length (Height)					
	As-Cast Length (Height)					
	Design Width					
	Form Set-Up Width					
	As-Cast Width					
	Design Depth (Thickness)					
	Form Set-Up Depth (Thickness)					
	As-Cast Depth (Thickness)					
	Out of Square					
	Block Outs					
	Squareness of Openings					
	End & Edge Details					
	Reinforcing Steel					
	Insulation					
	Reglets					
	Rustications					
	Haunches (Corbel)					
	Plates & Inserts					
	Lifting Loops					
Casting	Vibration Rating					
	Workability					
	Top Finish (Wet)					
FINISHED PRODUCT	Top Finish (Dry)					
	Bottom Finish (Dry)					
	Surface Textures					
	Color					
	Cracks or Spalls					
	Out of Square (Max.)					
	Camber or Deflection					
	Warpage					
	Bowing					
	Exposed Reinforcing or Chairs					
	Plates & Inserts					
	Chamfers & Radius Quality					
	Openings					
	Lifting Loops					
YARDING	Blocking					
	Finishing					
	Patching & Cleaning					
	Date Approval Stamp Applied					
LOADING	Blocking					
	Field Patching Required					
	Tie Downs					
	Driver Instructions					

USE BACKSIDE OF SHEET FOR REMARKS AND SKETCHES

APPENDIX D

Commentary

The information contained in this Commentary is not to be considered as part of the Manual in judging quality control procedures. It does provide additional information on current practices, responsibilities, materials and equipment on a few of the topics in the Manual. Articles in the Commentary are identified by the same Article numbers as in the Manual. Plant and regional differences will determine the applicability of this information.

DIVISION I—QUALITY CONTROL PHILOSOPHY

Section 1—Objectives and Method

1.1.1—General Objectives

It should not be assumed, because a well directed effort of inspection and testing is required to produce members of a uniform quality, that cost is increased. Control of manufacturing processes through uniform procedures will invariably show a first cost saving when compared to careless and haphazard practices. Further, the establishment of uniform methods at the required level of quality, and the use of these methods, will also result in reduced manufacturing costs when adopted as the norm in architectural precast concrete plants.

The best of materials and optimum design alone will not be sufficient to produce at minimum practical cost architectural precast concrete units of uniformly high quality. The actual production practices and procedures must be properly performed. Competent inspection and testing personnel operating under general supervision of management are required for proper coordination of production.

Section 2—Personnel

1.2.1—General

The skill, competence and conscientiousness of personnel involved in the manufacture of architectural precast concrete products will be reflected in the quality of the units produced. It is, therefore, important that the selection and/or training of personnel for positions of responsibility be made with care in order to attain a consistently high quality product and an efficient operation. Proper and responsible performance of persons involved in the manufacture of architectural precast concrete products relish and maintain a competitive market position for architectural precast concrete products, all persons engaged in the various phases of their design and manufacture should always be looking for methods to increase efficiency of plant equipment and labor, but not at the expense of product quality.

DIVISION II—PRODUCT CONTROL

Section 1—Testing

2.1.2.—Acceptance Testing of Materials

2.1.2.(2)—*Aggregates.* Specific gravity and absorption of normal weight coarse aggregates should be determined according to ASTM C 127 and for fine aggregate according to ASTM C 128; specific gravity factor of lightweight aggregate should be determined in accordance with procedures described in ACI 211.2–69; petrographic analysis should be made in accordance with ASTM C 295 to ensure that selected aggregates are durable, inert and free from iron oxide and other deleterious materials; in applicable regions, a test for potential alkali-aggregate reactivity should be made in accordance with ASTM C 227 or C 586 or C 289. Petrographic examination may eliminate need for alkali reactivity tests. The "quick chemical test" (ASTM C 289) may be used for the detection of glass aggregates which are expansively reactive with alkalies in the portland cement.

An additional test for staining potential of gravels or crushed carbonate rock is to immerse them in a lime slurry. If staining particles are present, a blue-green gelatinous precipitate will form within 5 to 10 min; this will rapidly change to a brown color on exposure to air and light. The reaction should be complete within 30 min. If no brown gelatinous precipitate is formed when a suspect aggregate is placed in the lime slurry, there is little likelihood of any reaction taking place in the concrete. These tests should be required if the aggregate does not have a record of successful prior use.

Precast units, although not normally exposed to salting or intense freezing and thawing, may be exposed to strong wet-dry cycling. Wet-dry sensitive coarse aggregates may crumble and such crumbling may be noticeable even if used in small quantities. Aggregates that have a wet-dry sensitivity, such as some shales, may be detected by alternating 24-hr. immersion of the aggregate in distilled water with a 24-hr. air-drying period for a minimum of 90 days.

2.1.2(6)—*Pigments and Pigmented Admixtures.* The ability to resist the action of lime can be tested by mixing 20 parts of cement with one part of the pigment, using sufficient water to form a buttery paste. The samples should be kept moist and observed for several days. If considerable fading occurs, the coloring materials are unsuitable. Under these test conditions, it is possible to develop efflorescence, which must be removed before the true color can be judged.

fading of a colored mortar on exposure to sunlight for 1 month is evidence that the pigment is unsuitable.

2.1.2(9)(b)—*Absorption.* A water absorption test of the proposed facing mixes may provide an early indication of weathering properties of the concrete (rather than durability). For the concrete strengths normally specified for architectural precast concrete (5000 psi), a reasonable water absorption should not be a problem unless cement-rich and/or high-slump concrete mixes are used.

Samples for testing. Three 4 x 8-in. cylinders or 4-in. cubes should be cast from each of the mixes being tested. If possible, samples should be cast in containers made from the mold material intended for the actual production unit. Test samples should be consolidated, cured and finished similarly to the products they represent. Test samples should be clean and free from any parting or form release agent or any sealer.

Test procedure. Specimens should be tested after 28 days. The specimens should be dried in an oven at a temperature between 180 to 225 F until the loss in weight in 24 hrs. is less than 0.1 percent. Test samples should be allowed to cool to room temperature, weighed and then submerged in water to one-half the height of the specimens. After 24 hrs. they should be submerged in water until water is flush with the top of the specimens. The water should in both cases be maintained at a temperature between 65 and 75 F. Following another 24 hrs., the specimens should be removed, the surface water wiped off with a damp cloth, and specimens weighed on a scale which has an accuracy within 0.1 gram.

The percentage absorption is the difference between wet weight and oven dry weight, divided by the dry weight and multiplied by 100. This figure may be transformed to volume percentage based on the specific weight of the concrete tested.

2.1.2(9)(c)—*Slump.* The Vebe consistometer subjects the concrete to a slump test on a vibrating table. (See *Recommended Practice for Selecting Proportions for No-Slump Concrete,* ACI 211.3.) The criterion of this test is the time in seconds required to consolidate the slump cone mass into a 9⅜-in. diameter cylindrical mass. Concretes that require a Vebe time of more than 6½ seconds may be difficult to consolidate properly with internal vibration. Concretes with Vebe times of less than 4½ seconds may be judged as having excellent consolidation characteristics.

2.1.3—Production Testing

Close control over gradation of aggregates is essential to avoid variations in surface texture and color in the finished product.

Compensation for surface moisture is particularly important for face mixes in architectural concrete where the amount of fine aggregates batched by weight may otherwise vary enough to seriously affect the color and texture of the finished face. (Note that free moisture on aggregates affects aggregate weights and slump control.) It is recommended that weighing hoppers be equipped with electric moisture meters calibrated to detect changes of 1 percent in the free moisture content of fine and coarse aggregate so corrections can be made and mixes adjusted at any time. Moisture metering devices based on conductivity will vary with the density of the aggregates. This type of moisture metering device is not recommended.

2.1.3(2)—*Concrete Strength.* Testing of concrete strengths by using test specimens is a critical part of the quality control program. Samples for strength tests must be taken on a strictly random basis if they are to measure properly the acceptability of the concrete. The choice of times of sampling or the batches of concrete to be sampled must be made on the basis of chance alone within the period of placement in order to be representative. If batches of concrete to be sampled are selected on the basis of appearance, convenience, or other possibly biased criteria, statistical concepts lose their validity. Obviously, not more than one test should be taken from a single batch, and water should not be added after the sample is taken.

In the absence of adequate test data for a correction factor, a factor of 80 percent of the cube strength should be used as a temporary conservative measurement to convert to standard cylinder strength for the same concrete.

Molds for making test specimens should be in accordance with applicable requirements of ASTM C 31 or C 470. Heavy gage reusable steel molds, rather than single use molds of paper or lightweight metal, are strongly recommended to provide cylinders that will indicate, more accurately, the strength of the concrete. The use of paper or light metal molds may reduce strength. As an alternate, horizontal molds of heavy gage metal, fitted with machined metal end plates and having a longitudinal slot approximately 2 in. wide at the top for placement of concrete may be used provided the strengths of cylinders from such molds are checked against cylinders cast in vertical molds and show equal or related strength. Use of horizontal molds with machined end plates will usually eliminate the necessity of capping cylinders and is of particular advantage in testing for strength of concrete at stripping.

Because of the danger of producing cracks and weakened planes, concrete with slumps less than about 1 in. should not be moved requirements of ASTM C 31 should be recorded in the test report. If vibrators are used, techniques should be developed to preclude segregation.

Preparation and testing of cubes should be as nearly consistent with the appropriate requirements for cylinders as possible, with the exception that the concrete be placed in a single layer of 4 in. Rodding or external vibration methods would then proceed as outlined in the ASTM designations. Internal vibration should not be applied to the consolidation of cubes.

Test specimens should be placed at random points alongside molds cured by steam or radiant heat. If there is any indication of variable heat, the proper location is close to the smallest volume of the unit being cured. In case of thin members, specimens should be placed in the coolest area. For heavy volumetric members, location of specimens for curing with these units is normally not critical.

It is recommended that an occasional set of test specimens be cured in the same manner as the precast panels in order that a comparison may be made betwen laboratory moist-cured specimens and the production units. For a correct comparison to be made, plant-cured and laboratory-cured specimens should come from the same sample.

Improperly heated capping compound generally results in defective caps. Improper temperature increases or decreases the viscosity of the compound and retards the escape of air bubbles. The voids created by air bubbles reduce the load-bearing capacity of the caps.

Occasionally, an isolated test result deviates so far from the average values as to be highly improbable. If the suspect specimen is one of a set of two companion specimens, it may be discarded only if the specimen shows evidence of questionable practices in sampling or in molding, curing, capping, or testing. Should both specimens in a test show any of these poor practices, the entire test should be discarded.

Impact hammer tests are of value primarily for qualitative comparisons within the same job rather than as quantitative measures of strength. The limitations and proper use of the hammer should be understood prior to its acceptance as a testing tool. Impact hammers are either of the spring-loaded or gravity type, of which the latter is generally considered more accurate, but which is normally limited to lower strengths and to testing on vertical faces. The calibration curve provided with the instrument to indicate the compressive strength from the reading obtained from the test hammer scale is not always precise. To be useful, the test hammer should be calibrated for the particular materials and mix designs on the job.

One method of calibration is to obtain rebound readings on standard test cylinders or cores immediately prior to their being tested in compression. Sixteen readings should be taken on the middle two-thirds of the cylinder surface along three vertical lines, 120 deg apart, while the cylinder is anchored in the testing machine by a load of at least 300 psi. The average reading from ten numbers, after discounting the three highest and three lowest readings, then is assigned to the cylinder compressive strength and a curve developed for a range of compressive strengths. The test hammer can be used horizontally, vertically upward and downward, or at any intermediate angle; however, readings in these various directions require separate calibration or correction charts. Rebound readings with the test hammer in a horizontal position generally are higher than those obtained in the vertical position. Even after a calibration curve is developed, individual points will deviate from the relation by 500 to 1000 psi. The method of curing and age at test should be kept constant when calibrating the impact hammer.

The area to be tested with an impact hammer should be smooth and uniform and preferably formed rather than finished. Areas exhibiting honeycombing, scaling, rough texture or high porosity should be avoided. Rock, sand, or air pockets will result in very low readings and the presence of air holes, large rock particles or reinforcement near the surface will cause erratic results. Concrete placed against wooden forms usually produces rebound numbers 10 to 20 percent lower than concrete cast against metal forms or finished with a metal trowel. This is especially evident with concrete of high compressive strength. However, the scatter of individual results on formed surfaces is lower. When necessary, a smooth surface should be produced by uniformly rubbing an area about 2 in. in diameter with a carborundum stone. This is a cumbersome procedure and can lead to large errors if not carried out uniformly.

If it is necessary to drill cores, their location should be determined by the Architect-Engineer to least impair the strength of the structure and exposed surface finish. Core holes can often be adequately patched without damage to the appearance or structural integrity of the element.

When possible, cores should be drilled so that the test load is applied in the same direction as the service load. Horizontally (in relation to casting) drilled cores may be up to 15 percent weaker than vertically drilled cores. Cores should be drilled with a diamond bit to avoid an irregular cross section and damage from drilling.

wooden wedges should be used to minimize the likelihood of damage and allow 2 extra in. of length at the broken end to permit sawing off ends to plane surfaces before capping. If any core shows evidence of damage prior to testing, it should be replaced.

The inclusion of reinforcing steel in the cores reduces the strength. The reduction tends to be larger for cores containing two bars rather than one. The cores, therefore, should be trimmed to eliminate the reinforcement whenever possible. Because the concrete in the structure will be dry under service conditions, the cores should be air dried (temperature 60 to 80 F, relative humidity less than 60 percent) for 7 days before test and should be tested dry.

2.1.3(3)—*Slump.* The slump test is the common method for controlling concrete consistency. It is also a good indicator of variations in water content from batch to batch. A change in slump may be indicative of a change in air content, or of changes in aggregate moisture content, gradation or density.

2.1.3(5)—*Unit Weight.* The unit weight is a quick and useful measurement for controlling quality. A change in unit weight generally indicates a change in either air content or aggregate weight. When unit weight measurements (ASTM C 138 or C 567) indicate a variation of more than 2 lbs. per cu. ft. for normal weight concrete or ± 2 percent for structural lightweight concrete, the air content should be checked first to establish if the correct amount of air has been entrained. If air contents are correct, then a check should be made on the aggregates to make certain that the unit weight, gradation, and moisture content have not changed. Results of these checks generally will reveal the cause of the variations in unit weight of concrete and indicate what mix adjustments need to be made.

From trial batching of specified lightweight concrete, the required freshly mixed unit weight is determined. Daily checks on the fresh unit weight of the delivered concrete, measured in accordance with ASTM C 567, provide a simple and satisfactory control measure. When total batch weight per cubic yard of concrete is divided by fresh unit weight, a quick check is made on concrete yield. This procedure is also recommended for checking yield of normal weight concrete.

2.1.4.—Special Testing

2.1.4(2)—*Concrete Coverage of Reinforcing Steel.* This test should be performed with an R-meter or covermeter and should be conducted preferably by the same technician each time. The calibration procedure for these instruments should be carefully followed to maintain measurement accuracy. The probable accuracy is within about ± 15 percent. However, care must be exercised to obtain proper reading during cold weather.

2.1.4(3)—*Freeze-Thaw Tests.* Since wall panels are oriented vertically, they are subjected only to occasional wetting and critical saturation (above 90 percent) is seldom reached. Thus, freeze-thaw durability tests of wall panels are generally not required. However, ground level panels may be subjected to splashing by deicing salts and to freezing conditions at moisture contents above critical saturation. Also, deeply recessed horizontal surfaces where snow accumulates may be a problem area.

Section 2—Inspection and Records

2.2.2—Scope of Quality Control Inspection

The number of persons necessary to perform inspecting services will vary with the size of the precast operation.

In general, there should be one full-time inspector for every 30 to 40 production employees. It also may be necessary for a records clerk to devote some portion of his time to inspection record keeping.

The important requisites are that all inspection services necessary to insure high quality products be provided, the functions of each inspector be clearly assigned, inspectors be given authority to require a uniform standard of quality in all phases of production, and adequate and accurate records be kept.

Section 3—Requirements for Finished Product

2.3.1—Tolerances

Tolerance is a permissible amount of variation from a specified or nominal characteristic. A tolerance may be expressed as an additive or subtractive (±) variation from a specified dimension or relation or as an absolute deviation from a specified relation. Tolerances should be established for the following reasons:

(1) Structural Conditions—Design for such factors as eccentric loading, bearing areas, and reinforcement and hardware locations should be based on specified maximum deviations for structural safety. The maximum accumulated deviation may be specified.

(2) Feasibility—In interfacing and joint performance.

(3) Visual Effects—The degree of deviation from theoretical requirements will be controllable. Large deviations are objectionable, whether they occur suddenly or cumulatively.

(4) Economics—Ease and speed of erection demand known accuracy in the dimensions of precast units.

(b) Contractual—To establish known acceptance limits.

The Architect-Engineer should be responsible for coordinating the tolerances for precast work with the requirements of other trades whose work adjoins the precast construction. In all cases the tolerances must be reasonable and realistic, within generally accepted limits. Tolerances given in this Manual are a guide only. The enforcement should be based on the judgment of the Architect-Engineer. The Architect-Engineer is able to decide whether a deviation from the allowable tolerances affects safety, appearance or other trades.

Where a project involves particular features sensitive to the cumulative effect of generally accepted tolerances on individual portions, the Architect-Engineer should anticipate and provide for this effect by setting a cumulative tolerance or by providing escape areas where accumulated tolerances can be absorbed. The consequences of all tolerances permitted on a particular project should be investigated to determine whether a change is necessary in the design or the tolerances are applicable to the project or individual components.

Careful inspection of the listed tolerances will reveal that many times one tolerance will override another. The specified variation for one element of the structure should not be applicable when it will permit another element of the structure to exceed its allowable variations. Restrictive tolerances should be reviewed to ascertain that they are compatible and that the restrictions can be met. For example, a requirement which states that "no bowing, warpage or movement is permitted" is not practical.

Tolerances for Manufacturing. Manufacturing tolerances are those needed in any manufacturing process. They are normally determined by economical and practical production considerations, and functional and appearance requirements. The actual tolerances should, however, be related to the amount of repetition, and the size and other characteristics of the precast unit. The cost of manufacturing to close tolerances decreases with increased repetition. Manufacturing tolerances are applied to physical dimensions of units such as thickness, length, width, squareness, and openings.

The Architect-Engineer should specify tolerances or require performance within generally accepted limits. Tolerances for manufacturing are standardized throughout the industry and should only be made more exacting, and therefore more costly, where absolutely necessary. These areas might be special finishes or appearance requirements, glazing details, and certain critical dimensions of open-shaped panels. For example, a special case may be honed or polished flat concrete walls where bowing or warping tolerances might have to be decreased to avoid joint shadows. Another special case might be tolerances for dimensions controlling the matching of open-shaped panels which may have to be less than the standard dimensional tolerances, unless the Architect-Engineer has recognized and solved the alignment problem as part of his design.

When considering casting tolerances (or dimensional measurements) the following items are significant:

(1) Length or width dimensions and straightness of a unit will affect the joint dimensions, opening dimensions between panels, and perhaps the overall length of the structure.

(2) Panels out-of-square can cause tapered joints and make adjustment of adjacent panels extremely difficult.

(3) Thickness variation of the precast unit becomes critical when interior surfaces are exposed to view. A non-uniform thickness of adjacent panels will cause offsets of the front or rear faces of the panels.

Tolerances for Interfacing with Other Manufactured Building Materials. Interface tolerances and clearances are those required for joining of different materials and for accommodating the relative movements expected between such materials during the life of the building. Typical examples are tolerances for window and door openings, glazing gaskets and reglets.

Where matching of the manufactured materials is dependent on work executed at the construction site, interface tolerances should be equivalent to erection tolerances. Where the execution is independent of site work, tolerances should closely match the standard tolerances for the materials to be joined. Fabrication and erection tolerances of other materials must be considered in design as the precast units must be coordinated with and must accommodate the other structural and functional elements comprising the total structure. Unusual requirements or allowances for interfacing should be stated in the contract documents.

Windows between open shape units where they will intersect a joint between units is an example which requires interface erection tolerances. A similar condition often occurs where precast concrete is interspersed with glass or metal curtain wall elements, as in many precast mullion projects. Close tolerances are often mandatory between the mullion and the glass or curtain wall. This condition demands additional flexibility that may be provided in the corner details. A solution which permits two or more corner elements to overlap and thus take up irregularities in the overall building dimension is recommended.

Where tolerances are independent of site conditions, they will depend solely on normal manufacturing tolerances plus an approglazing of an opening completely formed within a concrete panel. Such openings can be made to normal manufacturing tolerances. However, openings for aluminum windows should allow room for some temperature expansion of the sash. Fastening details should ensure that the aluminum is properly separated, or protected, from any other metals in the concrete panel in order to avoid possible electrolytic action.

Special tolerances for the planeness of concrete surfaces at the glass face should be provided when glazing is performed directly into the concrete. Close tolerances should govern the physical dimensions and alignment of the groove when neoprene gaskets are used in glazing. In both instances, a smooth concrete surface should be specified where sealants or gaskets meet the concrete surface to ensure water-tightness. Consideration must also be given to the glass manufacturing tolerances, which apply to both the thickness and size of glass, generally proportional to the glass thickness. Glass of $\frac{3}{8}$ in. nominal thickness, for example, may vary $\pm \frac{1}{32}$ in. in thickness and $\pm \frac{3}{32}$ in. from its nominal size dimensions. Similarly, the length and width of heat-strengthened or tempered glass may be $\frac{3}{16}$ in. more or less than their specified nominal dimensions.

Allowable variations from a perfect plane should be established after consultation with the glass manufacturer for double-insulating glass units, heat-absorbing or colored glass. The glazing solution selected should relate to realistic and attainable tolerances for the precast concrete.

2.3.2—Product Finish

Design and manufacturing procedures should be developed to counteract or remedy finish defects and/or problems, unless they are specifically desired by the Architect-Engineer or are inherent in the design of the unit.

(1) It is strongly recommended that all edges of precast units be designed with a reasonable radius or chamfer, rather than leaving them as sharp corners. Sharp corners chip easily both during handling and during service in the finished building. Mitred corners are difficult to manufacture and erect within tolerances which are acceptable from either an appearance or jointing standpoint. Concrete cannot be cast to a 45-deg. point because of the size of the aggregates. Therefore, this edge must have a cutoff or quirk. The size of the quirk return should never be less than $\frac{3}{4}$ in., nor less than 1.5 times the maximum size of the aggregate used in the concrete mix.

(3) Returns in some finishes will not appear exactly like the front face (down-face) due to casting techniques and aggregate shapes. This should be recognized and accepted within certain limits, because it may well influence the Architect's choice of shape, materials and finishes.

(6) Rust stains caused by reactive iron pyrites or other contaminants will occur where such contaminants are found as part of the aggregates. Rust stains may also be caused by particles of steel left by the aggregate crusher, pieces of tie wire from the cage assembly, or particles of steel burnt off in welding and accidentally left in the mold. These stains (and steel particles) should be removed from the surface as soon as visible. Rust stains caused by corroding reinforcing bars are not common. When reinforcing steel does corrode, it reflects shortcomings in design, concrete quality or workmanship. Rust stains due to corrosion of hardware should not occur when the hardware has been protectively coated or where it is entirely behind a weather-proofed joint.

(9) Units should be assessed for appearance during both wet and dry weather. The difference in tone between wet and dry panels is normally less with white concrete. In climates with intermittent dry and wet conditions, drying-out periods often produce blotchy appearances in all-gray cement units. This is particularly true of fine-textured surfaces. On the other hand, dirt (weathering) will normally be less objectionable in gray units. These comparisons are based on similar water absorption or density of white and gray concrete.

(14) It should be recognized that a certain amount of cracking may occur in precast concrete without being detrimental. With respect to acceptability of cracks, the cause should be determined as well as the stress condition a crack will be under with the precast unit in place.

The cement film on the concrete may develop surface crazing, i.e., fine and random hair cracks. A hair crack is defined as a surface crack of minute width, visible to the unaided eye but not measurable by ordinary means. The primary cause of these cracks is the shrinkage of the surface with respect to the mass of the concrete. This crazing has no structural or durability significance, but may become visually accentuated when dirt settles in these minute cracks. This is more true with white cement than with gray or a dark color, but the effect will depend on the character of the cement film. A relatively lean, properly consolidated concrete mix will show little crazing effect, in contrast to a mix rich in cement and water. Where crazing occurs, a horizontal surface will be affected more than a vertical surface due to the settlement of dirt. Crazing generally will not appear where the outer cement skin has constitute a cause for rejection.

Under additional strain, hair cracks may extend through to the reinforcement and thus become a through crack or cleavage crack. If the crack width is narrow, say not over 0.01 in., the structural adequacy of the casting will remain unimpaired, as long as corrosion of the reinforcement is prevented. Accordingly, precast wall panels containing through cracks up to 0.005 in. wide for surfaces exposed to the weather and 0.01 in. wide for surfaces not exposed to the weather should be acceptable, provided the reinforcement is galvanized or otherwise corrosion resistant. The limitation on crack size specified is for structural reasons. The esthetic limitation will depend on the texture of the surface and the appearance required. It is suggested that on coarse textured surfaces, such as exposed aggregate concrete, and on smooth surfaces comparable to the best cast-in-place structural concrete, the structural limitation would be esthetically acceptable. For smooth surfaces of high quality it may be desirable to limit cracking in interior panels to 0.005 in. In addition, it should be remembered that cracks will become even more pronounced on surfaces receiving a sandblasted finish.

Fractures generally develop from overstressing during handling. While some of these cracks may be repaired and effectively sealed, their acceptability should be governed by the importance and the function of the panel under consideration; the decision regarding acceptability must be made on an engineering basis as well as visual appearance.

Section 4—Damage and Repair

It is recommended that the precaster execute all repairs or approve the methods proposed for such repairs by other qualified personnel. Repairs should be done immediately following occurrence of damage. However, the decision on the time to perform the repairs should be left up to the precaster, who should be responsible for satisfactory final appearance.

Since repairs will be exposed to different curing environments than the already cured unit, it may be necessary to alter the color by blending of portland cements or the ratio of cement to aggregate from the original mix proportions, to provide the same general color as that in the rest of the surface. Sometimes other aggregates must be used to obtain uniformity. For shallow repairs it may be necessary to remove large sand particles that may hinder working the repair mix into the repair area. For smooth surfaces, concrete sand may be too coarse to use in the mortar. Coarse sand will impart coarse grain texture to the concrete and this will show up very conspicuously against the smooth surrounding concrete. Therefore, limestone or marble dust should be added to the sand or a fine silica sand substituted. These fine aggregates also increase the water requirements of the mortar and produce a whiter surface. In large areas requiring repair, the coarse aggregate would normally be in the repair mix. However, in small areas, it may be desirable to either eliminate the coarse aggregate or hand place the coarse aggregate into the surface of the repair.

White cement should be substituted for a portion of the gray or buff cement used in the original concrete. This is because the lower water-cement ratio of the repair causes it to dry darker than the original concrete. The proportion of white cement to be substituted should be determined by trial and error, making comparisons when the samples have dried out. An appropriate starting point would be 25 percent with adjustments made from this reference point. Due to the small amounts of cement required, all batching should be by weight for accuracy.

Trial mixes are essential to determine exact quantities. This is best determined by applying trial repairs to the project mockup or small sample panels (12 in. square) and selecting the appropriate mix after the trial repairs have been allowed to cure a minimum of 7 days, or preferably 14 days, followed by normal drying to 28 days. This is important because curing and ultraviolet bleaching of the cement skin have an effect on the finished color.

The repair mix should be mixed as dry as possible, with just enough water so that it will be tightly compacted when forced into place. The repair mix should be mixed in advance and allowed to stand with frequent manipulation with a trowel, without addition of water, until it has reached the stiffest consistency that will permit placing. Repair mix batches should be small enough to be placed in about 30 min.

When honeycombed areas are to be repaired, all loose material should be removed and the areas cut back until coarse aggregate will break under chipping rather than fall out, usually 1 to 2 in. The sides of the hole should be essentially vertical or slightly undercut. For exposed aggregate finishes, the repair area should be cut back to a depth a little deeper than the maximum size of exposed aggregate (i.e., for ¾ in. aggregate, the repair goes down 1 in.). Very thin edges (feather edges) should not be permitted; cutouts should be at least ¼ in. deep to provide a shoulder of sufficient depth to permit a smooth finish. In exposed aggregate finishes, the cutting back of the concrete in an irregular pattern may be desirable to cut back along the lines of the liner to hide the location of the repair.

After the hole is cut and dressed, all traces of loose debris and dust should be removed by brushing or blowing out with air. Then the area to be repaired and an area at least 6 in. wide surrounding it should be thoroughly saturated with water to prevent absorption of water from the repair mix into the surrounding concrete and to assure good bond. Use of a scrubbing brush with this operation is good practice (if a bonding agent is used, the area is left dry). After surface water has evaporated (approaches dryness) from the area to be repaired, a $\frac{1}{16}$ to $\frac{1}{8}$-in. bond coat of neat cement slurry, mixed to the consistency of thick cream, should be well brushed into the surface. When the bond coat begins to lose the water sheen, the premixed repair mix should be applied. The repair mix should be either vibrated or hand tamped for consolidation and to assure positive and uniform contact with the old surface. Vibration or tamping will bring water to the surface which will assist in finishing the relatively dry mixture.

Bonding agents such as epoxies, polyesters and water-resistant polymers may be desirable for large repairs. They should not be used integrally with the repair material, since a different texture and color as well as a different appearance when wet will be apparent, which will not fade with time (or may even change to an objectionable color). The bonding agent should be neatly applied to the dry surface of the repair area and allowed to dry to a tacky condition before applying the repair mix. Care should be taken to avoid the bonding agent from overlapping the edge. If, inadvertently, an epoxy bond coat reaches a soft rubber-like stage (no tackiness) prior to the placement of the repair, a second application of the epoxy bond coat is required.

The mix should be vigorously hand tamped to approximately the density of the surrounding concrete, since a variation in density will result in different absorption. The surface should be struck off so as to leave the repair slightly higher than the surrounding surface. To permit initial shrinkage, it should be left undisturbed for at least 1 hr. before being finally finished. For exposed aggregate finishes and liner textures, the compacted repairs are struck flush with the existing surface. For exposed aggregates, the damp, coarse aggregate then is hand placed, if not already in the repair mix itself. The coarse aggregate is patted into the surface with a small wood block and a wood or rubber float should be used to cover the aggregate with the patch mix.

After initial set, surfaces of repairs should be dressed manually to obtain the same texture as surrounding surfaces. The methods applicable for achieving the proper texture are dependent on the type of finish.

A smooth finish is very difficult to repair without showing because of variations in color and texture. A smooth surface may be obtained by wiping the repair with cheese cloth or a similar soft material, rubbing with carborundum stone, or grinding. For exposed aggregate finishes, after initial set of the repair mix, nylon bristle brushes may be used to expose the aggregate and texture the finish to blend with the surrounding concrete. A wet paint brush or sponge can also be useful to achieve texture. To obtain a sandblasted finish, the repair can be allowed to cure for 7 days, then a deep blast may be used on the patch, filling in with the proper matrix and then lightly brushing out to proper depth prior to initial set or, in some cases, the aggregate may be sandblasted prior to use in the mix.

Discrepancies in exposed aggregate finishes may be handled by the use of bushhammers, needle scalers, or grinders on hard spots, rather than by repairing. Exposure to a matching texture for sandblasted surfaces requires very light abrasive blasting of these hand-tooled areas to return the surface color to that of the surrounding abrasive blasted concrete.

When producing exposed aggregate elements with small-sized aggregates, about 1/8 in. to 1/4 in., it is often difficult to obtain uniform exposure with retarders. To restore the surface, it should be wetted, then a grout coat of cement, sand and water smeared and brushed into the surface to match the original concrete matrix. This operation also fills small voids that occur in the surface. Shortly after it has set, excess grout should be carefully brushed off the aggregate.

In those cases where a liner texture is specified, it may be necessary to use a liner to impress onto the repair the texture desired as the concrete sets up. If possible, the liner should be left in place to help in the curing. Where the surface is board-marked, this texture can be carried across a repair by striking off the surface with a straight-edge held parallel to the direction of the marks.

Metal tools shall not be used in finishing a repair to be exposed to view for the metal will sometimes darken repairs.

As an alternate to the above placing procedure, drypacking may be used where appropriate. Drypacking, i.e., the placement of a very stiff mortar by ramming or tapping it into place, should be used for deep holes not too large in area, rock pockets, and any hole which has a relatively high ratio of depth to area. Drypack should not be used for shallow depressions where lateral restraint cannot be obtained, for filling in back of considerable lengths of exposed reinforcement, nor for filling holes which extend entirely through method of repair usually will be satisfactory because very little drying shrinkage will occur.

Drypack is usually a mix (by dry volume or weight) of 1 part cement to 2½ parts sand that will pass a No. 16 screen. Only enough water should be used to produce a mortar which will stick together on being molded into a ball by a slight pressure of the hands and will not exude water but will leave the hands damp. The proper amount of mixing water and the proper consistency will produce a filling which is at the point of becoming rubbery when the material is solidly packed. Any less water will not make a sound, solid pack; more water will result in excessive shrinkage and a loose repair. Drypack mortar should be placed and packed in layers having a compacted thickness of about ⅜ in. Each layer should be solidly compacted over its entire surface by use of a hardwood stick and a hammer. Metal tampers are not suitable, as they tend to polish the surface, thus making the bond to successive layers less certain.

Moist curing of a repair may be accomplished by covering with a "poultice" of damp flannel and polyethylene taped to the concrete, being careful not to wash-out the repair. In any event the curing method should be tested on the trial repairs placed in the mockup. Non-staining membrane compounds may be sprayed over a repair and later removed by scrubbing with soap and water or an acid wash before delivery, if the rest of the unit was so treated.

Heat lamps to maintain approximately 50 F to 75 F are recommended for curing repairs in cold weather. It is preferable that placement of repairs should not be made when direct sunlight is on the area to be repaired. Methods such as sunshades should be considered to protect repairs from the hot sun and keep the area cool before and after repairing.

The repaired areas initially will be darker than the surrounding concrete. This color variation can be expected due to the different age and curing conditions for the repair. Over a period of weeks, repairs will lighten to the point of matching the existing concrete.

Cleaning should not be started until 3 to 7 days after repairs. Whatever method is used, extreme caution is necessary to ensure that the repair is not overworked or discolored. In some cases, cleaning of areas with a brush or brush and concrete cleaner may be sufficient to remove objectionable laitance. Acid cleaning may be used if the rest of the unit was so treated.

The epoxy injection process is applicable to all cracks wider than 0.002 in., depending on temperature of substrate and viscosity of epoxy being used. The first step in filling a crack by injecting epoxy adhesive should be to clean the cracked areas as thoroughly as possible and then provide a temporary surface seal on all faces of the crack so that the liquid resin will not leak and flow out of the crack prior to gelling and curing. If unexposed faces of the concrete cannot be reached, crack repair by pressure injection is extremely difficult unless special steps are taken. There are two methods used to provide this seal:

(1) Frequently, the cracks are Vee'd or routed to a depth of approximately ½ in. and a width of approximately ¾ in. by the use of light chipping hammers or a grinding tool. The Vee'd crack is then filled with a non-sagging epoxy adhesive compound or mortar which is applied like putty and then struck off flush with the concrete surface. This type of seal is used most frequently where very high injection pressures are expected.

(2) An alternate method of sealing the surface is to use a seal which is merely applied to the face of the crack and completely bridges the crack. Where possible, the seal is applied to both faces. Frequently, the material used here is also a non-sagging epoxy adhesive which sets rapidly. In some cases a strippable thermoplastic seal is used where the sealing material is applied at an elevated temperature.

In order to inject the adhesive material through the surface seal, entry ports must be provided. These entry ports are positioned along the crack at intervals at least equal to the depth of the member. This will ensure that epoxy injected into one port will flow through the full thickness of the member before flowing out of the next port. Three methods are in general use:

(1) One method, which is always used in conjunction with Veeing the crack, is to drill a hole into the crack approximately ¾ in. in diameter and to a depth of ½ to 1 in. below the apex of the Vee'd section, into which a fitting such as a pipe nipple or tire valve stem is bonded with an epoxy adhesive. These fittings are bonded with the same epoxy adhesive used to fill the Vee'd portion of the crack.

(2) When the cracks are not Vee'd, a method frequently used to provide an entry port is to bond a fitting flush to the concrete face over the crack.

(3) A third method is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

The epoxy grout may be mixed either by batch or continuous mixing and injected using paint pressure pots, air- or hand-actuated caulking guns, or hydraulic pumps.

on when the A and B components of an epoxy system react together. In a thin film on a cold substrate, the heat generated will not be noticeable.

The colder the environment the slower the material cures, with different formulations or product lines having various lower limits to the temperatures at which all reaction ceases. Some formulations will cure at reasonably low temperatures and, if frozen, won't expand and spall concrete sections but just lie dormant until the temperature rises enough to get the reaction going again.

Prior to mixing, the directions on the labels should be carefully read. Ensure that the shelf life of the product has not expired, and that both the A and B components are in the correct proportions and are meant to be blended together (i.e., both components are identified by the same product trade name or number). Mix in containers that the material is packaged in, or else in clean, dry containers. If required, sand or aggregates should be added after the A and B components have been thoroughly blended. Pure epoxies (no sand added and no solvent in formulation) have a pot life of from 12 to 20 min. at 70 F. If large quantities of sand are added, the pot life may be doubled. If large amounts of solvent are in the formulation, pot life can range from 30 min. to 8 hrs. The pot life can be extended by cooling the material in a cold water or ice bath, but the viscosity will change and application may become difficult. Conversely, a faster cure (and shortened pot life) will result if the epoxies and sands are heated before being applied to the repair areas. All tools and equipment should be kept continuously clean with solvents.

If the crack is vertical, the injection takes place from the bottom up through adjacent ports. Care must be taken not to trap air pockets. With horizontal cracks, injection proceeds from one end of the crack to the other through adjacent ports. The operator can be assured that the adhesive material has travelled to the full depth of the concrete member when material appears at the next port. At this time the first port should be plugged and injection begun at the second port. This procedure should be used until the entire crack or void in the concrete is filled. The crack is considered full when pumping pressure can be maintained. Inability to maintain pressure indicates that the adhesive material may be leaking out through a broken seal or vent hole, draining into connected cracks, or passing through the member into voids on the other side.

During the injection operation it is very difficult to be sure that the crack is completely full. Experience of the applicator is very important. Although some work has been done on sophisticated methods, such as ultrasonic testing to determine whether or not a crack has been filled, the only practical method available is by drilling concrete cores. It is absolutely necessary when assurance of a sound structural bond is required. After the epoxy adhesive has cured, the temporary surface seal and ports are scraped off leaving the face of the concrete smooth and unmarred except for the trace outline of the crack. Epoxy should be examined for adequacy of hardening.

Epoxy compounds sometimes contain chemicals that can cause mild to severe dermatitis with some people if their skin is exposed for long periods of time to the resins. Also, solvents are used to clean up tools and equipment after usage and normal precautions should be used when working with such powerful solvents as M.E.K. or Xylene. Long sleeved clothing, rubber gloves and safety goggles shall be worn.

Frequently a broken-off piece can be "glued" back in place using an epoxy bonding agent. Broken surfaces of unit and piece should both be painted with the adhesive. Enough epoxy should be applied to both surfaces to have some squeeze out of the joint when mated pieces are clamped together. An epoxy with a thick enough consistency should be selected to prevent sagging or running on a vertical surface. Self-leveling formulations should not be used. In some cases it may be preferable to drill into the element itself to get some anchorage for bonding broken pieces.

Section 5—Design

2.5.1—Design Considerations and Responsibilities

Local practices regarding the design of precast concrete vary considerably across North America as do, to a lesser degree, relevant codes or statutes governing professional design and the responsibility of manufacturers. Hence the points made in this section should be evaluated for conditions applicable to the particular location or to individual projects.

In the interest of both precaster and Architect-Engineer, the design responsibilities of each party should be clearly defined. It is recommended that this be done in the contract documents.

The responsibilities of the Architect-Engineer are subject to his contractural relationship to the Owner and also to the rights, duties, obligations and responsibilities assigned to him in the contract documents. Exceptions to items of responsibility are clarified in a written instrument to which the Owner and Contractor are parties and in the Owner/Architect-Engineer agreement.

Responsibility for both structural and esthetic design of architectural precast concrete should rest with the Architect-Engineer who should:

(2) Establish the standards of acceptability. The Architect-Engineer's right to reject work is provided to enable him to fulfill his duty to the Owner in endeavoring to guard the Owner against defects in the work which will render the building, or any portion of it, incapable of use in the manner and for the purpose for which it was intended, or from having the intended appearance.

(3) Determine the part, if any, played by the precast concrete in the support of the structure as a whole.

(4) As part of his design, allow for the effect of difference in material properties, stiffness, temperatures, and other elements which might influence the interaction of precast concrete units with the structure.

(5) Determine load reactions necessary for the accurate design of both reinforcement and connections.

(6) Evaluate thermal movements as they might affect requirements for joints, connections, reinforcement and compatibility with adjacent materials.

(7) Analyze the water-tightness of exterior concrete wall panel systems, evaluating joint treatment, including the performance of adjacent materials for compatibility in joint treatment, and the proper sealing of windows and other openings, except where such systems are manufactured and marketed as proprietary items.

(8) Design the supporting structure so that it will carry the weight of the precast concrete as well as any superimposed loads; include provisions for deflection and rotation of the supporting structure during and after erection of the precast concrete.

(9) If the stability of the structure is dependent on the sequence or method of erection, design the supporting structure to withstand the temporary loading conditions that might be encountered as a result of the sequence of erection and/or the sequence of loading of the structure. However, the General Contractor is responsible for the construction means, methods, techniques, sequences, or procedures.

(10) Make selection of surface finishes recognizing certain limitations in materials and production techniques in regard to uniform color, texture, and performance, especially the limitations which are inherent in natural materials.

(11) Make selection of interior finishes defining the area of exposure and the interior appearance for occupancy require-

ments, again recognizing material and production limitations.

(12) Design for durable exterior walls with respect to weathering, corrosive environments, heat transfer, vapor diffusion, and moist air or rain penetration.

(13) Design sandwich wall panels for their proper structural and insulating performance.

(14) Review and approve all precasters' drawings as required in the specifications.

(15) Specify dimensional and erection tolerances for the precast concrete, and tolerances for supporting structure and contractors' hardware. Any exceptions to PCI standard tolerances should be clearly identified.

Contract drawings should provide a clear interpretation of the configuration and dimensions of individual units, their relation to the structure, and to other materials. The drawings should indicate the location of all joints, both real (functional) and false (esthetic). The drawings must supply the following information:

(1) All sections and dimensions necessary to define the size and shape of the unit.

(2) Joint details between units.

(3) Finish required on all surfaces and a clear indication of the surfaces that are to remain exposed.

(4) Details of corners of the structure.

(5) Details of connections to the supporting structure (optional).

(6) Reinforcement of units (optional).

(7) Jointing to other materials.

(8) Unusual conditions.

This information should be sufficiently detailed to enable the precaster to produce the units and for the erector to install them. In most instances the precaster will make his own erection drawings to identify the information for precast concrete and translate these details into production and erection requirements.

Whether all reinforcement and connection details are shown by the designer or left entirely to the precaster is the prerogative of the Architect-Engineer. This condition may be determined by local practices and included in the project specifications. If reinforcement and connections are not detailed, the requirements for the design must be clearly identified. The amount of space allowed for connections should also be indicated.

It is generally recommended that the Architect-Engineer define dead and live loads and describe a section adequate to receive loads, and design the connection for each typical unit. This approach provides a design compatible with structural capability, concrete

Architect-Engineer and manufacturer

Contract Information Supplied by Architect-Engineer	Responsibility of the Manufacturer
OPTION I	
Provide complete drawings and specifications detailing all esthetic and functional requirements plus dimensions.	The manufacturer shall make erection and production drawings (as required) with details as shown by the Architect-Engineer. He may suggest modifications that in his estimation would improve the economics, structural soundness or performance of the precast installation. The manufacturer shall obtain specific approval for such modifications. Full responsibility for the precast design, including such modifications, shall remain with the Architect-Engineer.
OPTION II	
Detail all esthetic and functional requirements but specify only the required structural performance of the precast units. Specified performance shall include all limiting combinations of loads together with their points of application. This information shall be supplied in such a way that all details of the unit can be designed without reference to the behavior of other parts of the structure.	The manufacturer has two alternatives: (a) Submit erection and shape drawings with all necessary details and design information for the approval and ultimate responsibility of the Architect-Engineer. (b) Submit erection and shape drawings for general approval and assume responsibility for his part of the structural design, i.e., the individual units but not their effect on the building. Firms accepting this practice may either stamp (seal) drawings themselves, or commission engineering firms to perform the design and stamp the drawings. The choice between alternatives (a) and (b) shall be decided between the Architect-Engineer and the manufacturer prior to bidding, with either approach clearly stated in the specifications for proper allocation of design responsibility.

OPTION III	
Cover the required structural performance of the precast units as in Option II and cover all or parts of the esthetic and functional requirements by performance specifications. Define all limiting factors such as minimum and maximum thickness, depths, weights and any other limiting dimensions. Give acceptable limits of any other requirements not detailed.	The manufacturer shall submit drawings with choices, assuming responsibilities as in Option II.

cover, hardware protection, appearance, and clearance for mechanical services. In addition, it will establish parameters for modifications which may be suggested by the precaster to suit his production and erection techniques, and at the same time satisfy project design requirements. Design deviations requested by the precaster or erector will be permitted only after the Architect-Engineer's approval of the proposed change.

The general conditions of the construction contract usually state the responsibility of the constructor (usually the General Contractor) in coordinating the construction work. The General Contractor is responsible for project schedule, dimensions and quantities, coordination with all other construction trades, and for the adequacy of construction means, methods, techniques, sequences, and procedures of construction, in addition to safety precautions and programs in connection with the project. The precast manufacturer shall not proceed with fabrication of any products prior to receiving approval of erection drawings by the General Contractor.

The constructor should:

(1) Be responsible for coordinating all information necessary to produce the precast erection drawings.

(2) Review and approve all precast shop drawings which include the scheme of handling, transporting, and erecting the precast concrete, as well as the plan of temporary bracing of the structure. (Handling and transporting responsibilities depend on whether precast is sold f.o.b. plant or jobsite.)

(3) Be responsible for the coordination of dimensional interfacing of the precast concrete with other trades.

(4) See that proper tolerances are maintained to guarantee

drawings.

The constructor must be responsible for coordinating complete precast erection drawings so that related items are transmitted by him to the designer in one package. The constructor must immediately notify the precaster of any deviations found in dimensions due to plan or construction errors or changes to the structure.

Any additional design responsibility vested with the precast concrete manufacturer should be clearly defined by the Architect-Engineer. Additional design responsibility for the manufacturer may occur when the Architect-Engineer uses methods of communication as listed in Options II and III in Table D1.

Most precast work today is covered in Option I. Option II (b) may occur when no engineer is involved with the Architect for panel design, and where doubtful areas of responsibility therefore may exist. Under this option, the manufacturer should employ or retain a structural engineer experienced in the design of precast concrete, who will ensure the adequacy of those structural aspects of the erection drawings, manufacture and installation for which the manufacturer is responsible. Option III is not yet a common practice but might be used for design of systems buildings or with performance specifications.

Section 6—Prebid Samples

2.6.1—General

Due to individual preferences, differences in sources of supply, or different techniques developed in various plants serving the same area, the Architect-Engineer should not expect to select one sample and obtain exact matching by all precast concrete producers. If done, this may preclude the optimum quality from plants other than the one submitting the specified sample.

Many architects have developed a practice of making sample selection and approval just prior to bid closing. Thus, for a specific project, a specification requirement, and the approved manufacturers' names and corresponding sample code numbers, may be published in an addendum or approval list given in writing to the manufacturers.

This practice may result in a slight variation in color, aggregate or texture (but not necessarily quality) from different bidders, since the individual precaster, within specification limits, selects his materials and employs the placing and finishing techniques best suited to his operation. The Architect-Engineer, when making prebid approval of samples part of the specifications, should adhere to the following requirements:

(1) Sufficient time should be allowed for the bidder to submit such samples or information for approval. Time should also be provided to enable such approvals to be conveyed to the manufacturer in writing so that he can estimate and submit his bid.

(2) Any prebid submittal should be treated in confidence, and the individual producer's solutions and/or techniques protected both before and after bidding.

If the characteristics of submitted prebid samples in any way deviate from the specifications, the manufacturer should make this clear to the Architect-Engineer when submitting the samples and other required information. For proper evaluation and approval, the manufacturer should state his reasons for the deviations. Such deviations from the specifications may arise from reservations by the producer as to his ability to satisfy all conditions of the specifications based upon practical plant production reasons. Alternately, they may reflect his concern over controlling variation in either color or texture within specified limits, or reservations in regard to adequacy of specified materials, or even concern regarding the performance or weathering of the product in its final location.

The Architect-Engineer may request a date as described in Article 2.6.3 in order to evaluate these deviations. If such deviations and samples are approved, the original project specifications and contract drawings should be changed accordingly by the Architect-Engineer.

Since some samples are developed for specific projects with particular shapes or other characteristics, while others are more general for simple applications, it is the responsibility of the precaster either to make sure that the Architect-Engineer does not retain these specific project samples, or that they are clearly marked with respect to limits of application to prevent their use for unsuitable applications.

Some examples of use of samples for specific applications are sandblasted lightweight aggregate units for interior applications, or units that use mixes with lower compressive strength and/or higher absorption percentages for dry, non-corrosive atmospheric conditions, or the use of concrete elements in temporary buildings, such as exhibit halls.

DIVISION III—PLANT FACILITIES

Section 1—General Objectives and Safety

3.1.1—General

Quality production of architectural precast concrete elements requires experience in manufacturing and plant facilities which reflect current concrete technology. Facilities suitable for the production of precast units will vary widely from plant to plant. These facilities will be affected by the size, weight, and volume of the products produced in the plant, and by the climate and proximity of marketing areas.

The environment in which a man works has a very significant effect on the quality of his work. Better working conditions will result in higher quality work when combined with proper control and management direction.

3.1.2—Safety

PCI has an in-depth *Safety and Loss Prevention Manual* program. It outlines general safety practices as it relates to the precast concrete industry and existing Federal regulations.

This section is intended to outline some of the more important safety practices for precast concrete plants in a broad manner and cannot be considered to include every conceivable hazard that may be present in a precast concrete plant; however, the recognition of hazards, the establishment of good safety practices and the requirement that all personnel abide by safety rules will result in a more efficient and safer operation in any plant. The potential hazards discussed in this section are generally understood by producers and workmen alike; however, it is human nature that people who are constantly exposed to potentially dangerous situations tend, over time, to lose their conscious fear unless they are constantly reminded of the danger.

Section 2—Batching and Mixing Facilities

3.2.2—Storage and Handling of Aggregates

Unless uniformity of aggregates as batched is assured, production of uniform concrete is unlikely despite a high order of accuracy in measurement and superior performance in mixing and placing.

It is essential for effective control that handling operations minimize variations in undersize material outside each designated size. For fine aggregates, the accumulation of undersize material is in coarse aggregates due to segregation, breaking and chipping.

Stockpiles of coarse aggregate inevitably tend to accumulate an excess of fines near their bases. Enough of this fine material should be periodically removed and discarded so the coarse aggregate as delivered to the batching bins is within specified gradation limits.

3.2.4—Measuring Equipment

The range of tolerance control, weight control limitations of batching equipment and batching controls are covered in the *Concrete Plant Mixer Standards* of the Concrete Plant Manufacturers Bureau. These standards also specify the minimum size capacity per cubic yard of the rated batcher's capacity. (Batchers are rated in cubic yards of mixed concrete that can be produced. For example, a cement scale must have a scale capacity of at least 660 lbs. per cu. yd.)

It is common practice to use careful manual weighing when small batches are required so that, with care, 0.1 percent of scale capacity (one scale division) can be obtained. With most batching equipment, some degree of closer accuracy control is possible but is usually accompanied by a slowdown in the normal time required to batch. Another expedient is to use a mix formulation with a slightly higher cement content on small batches to obtain minimum required strengths to overcome the known equipment limitations.

With manual batching, the signal to terminate the material flow depends on the human element to anticipate the unregistered material passing the cut-off device. Thus, the accuracy obtainable is dependent on the skill of the operator and his desire to do a good job.

With automation, the controls should anticipate the various batching conditions and, although they often require more time to perform batching, can perform multiple functions at the same time, and are not subject to human frailties.

Manufacturers often provide a means to adjust the full gate opening, in order to gain the final cut-off control necessary for the variety of material sizes, while allowing for the use of the same size gate on all aggregate bin compartments. Two-stage cut-off with a final "dribble" feed control is also used. Other methods are an adjustable mid-air compensation for individual materials or a two-stage "fast" and "slow" gate, or combinations of these.

Lever system scales should be so designed that center of gravity of gross load always lies between load pivots. All beam type scales should be equipped with a tare beam, they should have provisions for indicating to the operator that the required load in the hopper is being approached by means of a graduated beam or dial showing at least the last 10 percent of the batch weight, and separate weighing beams for each ingredient of a batch to be weighed on the same scale. Beam poises should be corrosion resistant, equipped with positive and accurate holding devices, and capable of being set to the minimum graduated interval, which shall be not greater than 0.1 percent of capacity with a clear interval of not less than 0.03 in. Balance indicators should be sufficiently sensitive to show movement when weight corresponding to 0.10 percent of scale capacity is placed in the batch hopper at a load equal to or above 50 percent of scale capacity; pointer travel of balance indicators should be at least 5 percent of net rated capacity of largest weigh beam or 200 lbs., whichever is less, for underweight and 4 percent or 100 lbs., whichever is less, for overweight; and provision should be made for damping oscillation of the indicator pointer.

Dial-indicating scales should have the dial head mechanism enclosed so as to be dust tight. Dials should indicate load in batcher continuously from zero balance to full weighing capacity of the scale. Dial faces should have a minimum of 1000 graduations on a circular reading line at clear intervals of not less than 0.03 in.

Digital indicators or displays should be protected from dust with numbers large enough for good readability. The minimum numerical increment should be equal to or less than 0.1 percent of scale capacity.

Load-cell scales should be arranged to transmit load to one or more cells directly, or through a system of levers, in such a way that the cell system registers the entire load accurately on the load-indicating device; load cells should be indicated by manufacturer to be accurate throughout the range of temperatures to which normally exposed during plant operation.

Dispensers for liquid admixtures may measure either by volume or weight. Powdered admixtures should be measured by weight. Admixtures should, preferably, be in liquid form. Modern liquid admixture batching equipment incorporating effective controls and interlocks have virtually eliminated the requirement for weighing admixtures in the powdered state.

If more than one admixture is being used through a single dispenser without flushing of the dispenser with water after each cycle, it is necessary to ascertain that the admixtures are compatible and that the mixing of the admixtures prior to introduction into the concrete will not be detrimental.

Automatic equipment for measuring and dispensing admixtures is strongly recommended, provided dispenser is equipped with a visual means of providing a gross check to the batchman of the amount of admixture batched during each cycle, within ±20 percent. This gross check is required to help the batchman prevent function in any batch, which could cause great changes in fresh and/or hardened concrete properties.

The following are examples of how the gross check might be provided: (a) collecting the measured quantity of admixture in a calibrated container during each cycle and holding it for a short period to permit a visual check; and (b) measuring the dispensed quantity through the use of an independent meter to obtain a rough check on the amount measured by observation of a volumetric indicator.

Section 3—Production and Curing Facilities

3.3.2—Mold Fabrication and Storage

Mold construction, whether or not a part of the manufacturers' operations, must meet rigid specifications and tolerance checks established by the engineering section designing them. Storage for special molds, special patterns or other items that are very expensive should be considered when the project may be expanded in the future or where they may be reused in some form at a later date.

3.3.4—Casting Area and Equipment

Provision should be made to control the temperature with reasonable accuracy, since chemical retarders and form-release agents may react differently under varying temperature and humidity ranges. To meet the provisions of Division V, it is necessary to provide heating and/or proper ventilation for the casting area and the molds, depending on the geographic location of the plant.

It is a general rule for concrete vibration that satisfactory and more or less comparable results can be obtained using frequencies and amplitudes within a relatively wide range provided that a certain intensity of vibration (acceleration) is attained. The amplitude should also exceed a certain minimum value. Frequency alone provides no conclusive measure of a vibrator's effectiveness and vibrator suppliers should state such inter-related factors as centrifugal force, amplitude, and/or acceleration so that comparisons can be made between various vibrators. The fines of a mix (cement and fine aggregate) are affected more by high frequency, low amplitude vibration than are coarse aggregate particles.

Before a vibratory unit is put into use, and periodically, it should be checked to verify that it is working properly. Frequencies can be measured with a vibrating reed or resonant reed tachometer, or stroboscopes which work with rapid flashes of light emitted with varying frequency. When the vibrating object seems to be stationary its frequency is the same as that of the stroboscope and can be read from a scale.

The frequency of an internal vibrator operating in concrete can be determined by holding the tachometer against the back end of the vibrator while it is almost submerged; for an air vibrator, holding the device against the hose is equally satisfactory. This measurement should be taken just before the vibrator is withdrawn, which is always the fastest speed while it is operating in concrete.

The amplitude of an internal vibrator varies linearly along the head, the maximum value occurring at the tip. A visual effect scale (optical wedge) available from vibrator manufacturers may be attached to the vibrator head to determine the amplitude. Lines on the scale appear to be wider lines or bands when the vibrator is operating, and the scale is such that the amplitude can be determined directly.

There is at present no simple method for determining the amplitude of a vibrator operating in concrete. It is therefore necessary to use the amplitude while operating in air, which is somewhat greater than the amplitude in concrete. This amplitude may be either measured or computed. While not strictly correct for internal vibrators, the centrifugal force at a certain frequency may be used as a rough overall measure of the output of a vibrator.

For flexible shaft electric and most air internal vibrators, an amplitude measurement should be taken near the tip and another near the back end of the head, and these results averaged.

For the motor-in-head and pendulum types, where the eccentric is near the tip, the amplitude will generally be relatively large at the tip, it will decrease rapidly until a node (point of zero amplitude) is reached near the back end, and the amplitude will increase to a relatively small value at the extreme back end. The node can be verified and located by moving one's hand over the surface of a vibrator. If the node is less than one-fifth of the head length away from the back end, the average amplitude may be taken as one-half the measured tip amplitude. If the node point is at a greater distance from the back end, a second measurement near the back end should be taken. The average amplitude can then be determined from the two measurements.

Internal vibrators are generally called immersion, poker or spud vibrators. One of the most commonly used types is the flexible shaft type where the electric motor is outside the vibrator. A flexible shaft leads from the motor into the vibrator head where it turns the eccentric weight. A universal, 110 volt, single phase, 60-cycle per sec. motor is used, and the speed of this vibrator when operating in air is quite high—in the range of 12,000 to 17,000 developed, the vibrator may burn up if operated carelessly outside the concrete. However, when the vibrator is operating in the concrete, the motor is under load and the frequency is generally reduced by about one-fifth.

The motor-in-head vibrator has the motor in the vibrator head, as the name implies. Most motor-in-head vibrators are high-cycle units. This means that 180-cycle current is required for their operation instead of the usual 60-cycle commercial power. They use induction motors and operate at a speed in concrete of about 10,000 vpm; this is only about 5 percent less than the free speed (speed in air). The high-cycle current is obtained by passing commercial power through a frequency converter, or through the use of a special generator. Motor-in-head vibrators operating on 60-cycle current are also available, but they have less capability than high-cycle units.

The principal requirement for an internal vibrator is effectiveness in consolidating concrete—it should have an adequate radius of action, and it should be capable of "melting down" and de-aerating the concrete quickly. Available evidence strongly indicates that the effectiveness of an internal vibrator depends mainly on the head diameter, frequency, and amplitude. The amplitude is largely a function of the eccentric moment and head weight.

To achieve a sufficiently large radius of action in the concrete mix, the internal vibrator should have high frequency, amplitude and acceleration. Accelerations between 100 and 250 g are common. However, at excessively high frequencies the vibrating effect is reduced and an optimum frequency range exists for internal vibrators. At all frequencies, an increase in amplitude results in an increase in the effective radius of action. Given constant vibration data, the radius also increases with increased tube weight and diameter. The optimum frequency is lower for vibrators of large diameter and higher for those of small diameter.

The most suitable size of internal vibrator (tube diameter) is determined by the formwork dimensions and the spacing between reinforcement bars. The most common types of internal vibrators have diameters of ¾ to 3½ in. The larger the tube diameter the greater the radius of action and consequently also the output of work. As a rule, then, it is advisable to use the largest tube diameter permitted by the dimensions of the formwork and the spacing between reinforcement bars.

The vibrator manufacturer's catalog should include the physical dimensions (length and diameter) and total weight of the vibrator head, amplitude, frequency in air and approximate frequency in concrete, and centrifugal force at these two frequencies to permit comparisons between competitive units.

The catalog should also include certain other data needed for proper hookup and operation of the vibrators. Voltage and amperage requirements, and wire sizes (depending on the length of run) for electric vibrators should be given. For air vibrators, compressed air requirements in pounds per square inch and cubic feet per minute should be stated, as well as size of piping or hose (also depending on the length of run). Speed should be given for gasoline engine driven units.

External vibrators may be divided into form vibrators, surface vibrators and vibrating tables.

Form vibrators are external vibrators attached to the outside of the form or mold. They vibrate the form, which in turn transmits the vibration to the concrete. Extremely rugged forms are required where high amplitude vibration is used. The effective penetration in the concrete of the vibrations ranges from 8 to 24 in.

Rotary type vibrators are preferred because the reciprocating type is very hard on forms. Rotary type vibrators may be either pneumatically, electrically or hydraulically driven.

In the pneumatically driven models, centrifugal force is developed by a rotating cylinder or revolving eccentric weight. These vibrators generally work at frequencies of 6000 to 12,000 vpm (100 to 200 Hz). The frequency may be varied by changing the air pressure, usually by adjusting the air supply valve. The amplitude and centrifugal force may be varied by changing the eccentric weight.

The electrically driven models have an eccentric weight attached to each end of the motor shaft; generally, these weights are adjustable. The end covers are removed and the eccentrics can easily be set at different centrifugal forces, either by altering the relative angular position of the eccentrics or by changing the mass of the eccentric. In most cases induction motors are used, and the frequency is 3600 vpm (60 Hz) (3000 vpm for 50-cycle current). Higher frequency vibrators operating at 7200 or 10,800 vpm (120 or 180 Hz) are also available, which require a frequency converter. In addition, there are electric form vibrators powered by single phase universal motors and having frequencies of 6000 to 9000 vpm (100 to 150 Hz), depending on load. Using low-frequency (3600 vpm), the amplitude will be greater for a given centrifugal force than when using high-frequency vibration.

The hydraulic models are driven by a hydraulic motor which turns an eccentric on a shaft. The advantage is extremely low noise level, similar to an electric motor, but it is infinitely variable in

The manufacturer's catalog should include the physical dimensions, weight, amplitude and centrifugal force. For pneumatically driven models, the frequency in air and approximate frequency under load should be given. For electric models, the frequency at the rated electric load should be stated. The centrifugal force at the given frequency values should be provided as well as the electrical data for voltage and amperage.

The effectiveness of form vibration depends mainly on the acceleration imparted by the form to the concrete, provided the amplitude of the form is adequate—at 10,000 vpm the form should have an amplitude of about 0.003 in., at 7200 vpm the form should have an amplitude of about 0.007 in. and at 3600 vpm the form should have an amplitude of about 0.03 in.

The acceleration of a form is a function of the centrifugal force of the vibrators as related to the weight of form and concrete activated. The acceleration of the form should be at least 5 g. It is advisable to check the frequency and amplitude at several points on the form, using a vibrograph or other suitable device. The following empirical formulas have been useful in estimating the centrifugal force of form vibrators needed to provide adequate consolidation:

1. For plastic mixes:
   Centrifugal force = 0.5 [(weight of form) + 0.2 (concrete weight)]
2. For stiff mixes:
   Centrifugal force = 1.5 [(weight of form) + 0.2 (concrete weight)]

Any formula used should be checked against field experience. It is suggested that the vibrator manufacturer be contacted furnishing him with drawings of the unit to be vibrated, and soliciting recommendations as to the size, quantity, and location of vibrator units.

Surface vibrators may be a (1) vibrating screed consisting of a single or double beam or plank long enough to span the width of the unit on which a vibrator is mounted, (2) pan type vibrator consisting of a horizontal pan (or series of pans) to which a vibrator is attached and spanning the width of the unit but resting on the unit without touching the forms, (3) small plate or grid vibratory tampers (usually a few square feet in area) powered by an external vibrator.

The compaction effect of surface vibrators is proportional to the vibrator weight times amplitude times frequency divided by the forward speed of the machine. Concrete of low slump with a high proportion of cement requires a comparatively heavy surface vibrator. A large amplitude is needed, especially for the stiffer consistencies, to attain a considerable depth of compaction. Frequencies in the range of 3000 to 6000 vpm (50 to 100 Hz) have been found most satisfactory. Vibrating screeds usually work best with accelerations of about 5 g. The size or length of the baseplate and its shape also effect compaction results and surface finish.

A vibrating table normally consists of a steel or reinforced concrete table with external vibrators rigidly mounted to the supporting frame. The table may serve as part of the mold and should consist of sheet steel or a wooden platform. Usually, however, a separate mold rests or is fastened to the top of the table. The vibration is transmitted from the table to the mold and thence to the concrete.

It is important that the vibrating table be very rigid and of heavy-duty construction; however, it should be sufficiently flexible to permit vibrations to spread uniformly over the entire surface of the table.

If the centrifugal force and weight of the table are known it is possible to calculate the weight of concrete and formwork that can be put on the table. Neither the weight of the concrete nor the weight of a form placed loosely on the table, affects the vibrations to the same degree as the weight of a form attached rigidly to the table. Different formulas are therefore given for vibrating tables with rigidly attached forms and for vibrating tables with forms placed loosely on them (see Table D2).

The question of whether concrete forms should be rigidly attached to the table or placed loosely has been the subject of much

Table D2. Formulas for calculating necessary centifugal force for vibration on vibrating tables or vibrating beams

Vibrating table or vibrating beam of rigid design	Vibrating table of flexible design
Loose form	
$C = k(F_b + 0.2F + 0.2B)$	$C = \frac{k}{4}(F_b + 0.2F + 0.2B)$
Fixed form	Where: C = centrifugal force F_b = weight of vibrating table F = weight of form B = weight of concrete k = 2 to 4
$C = k(F_b + F + 0.2B)$	

strength and density; however, the difference amounts to only a few percent. Further, a greater weight of formwork and concrete can be used when forms are placed loosely on the table. On the other hand, this method gives rise to greater stresses on both form and table due to the shocks that occur when the table vibrates. It is therefore difficult to lay down any firm rules concerning rigid attachment or loose placing of the forms on vibrating tables. It has also proved difficult to design simple, fast and effective methods of attaching loose forms to vibrating tables.

Various frequencies may be considered for the motor vibrators on vibrating beams or vibrating tables. A frequency of 3000 vpm (50 Hz) gives better compaction effect and substantially faster vibration for a given centrifugal force than a frequency of 9000 vpm (150 Hz). The larger amplitude obtained with a frequency of 3000 vpm (50 Hz) is particularly important in the manufacture of sandwich units in which insulation makes effective vibration of the top layer of concrete more difficult. In this case, a frequency of 1500 vpm (25 Hz) has also been used with good results.

The frequency of rigid vibrating tables is normally in the range of 3000 to 6000 vpm (50 to 100 Hz). Effectiveness of table vibration depends mainly on the acceleration imparted by the table to the concrete, provided the amplitude is adequate. Without load, the table should have an acceleration of 5 to 10 g. The minimum acceleration will depend on the consistency of the mix and also on the dimensions of the form. A certain minimum amplitude has also proved to be necessary. Like acceleration, this is dependent on the consistency of the mix.

Form vibrators on flexible vibrating tables may operate either at a frequency of 3000 to 3600 vpm (50 to 60 Hz) or at a high frequency. When operating at 3000 to 3600 vpm the amplitude will be relatively large for a given centrifugal force, which is advantageous from the point of view of compaction effect and vibration time. High-frequency vibrators, electric or air-driven, may be suitable especially when flexible vibrating tables with large surfaces are to be vibrated. It is consequently difficult to give a general recommendation regarding suitable vibration frequency.

When concrete sections of different sizes are to be vibrated, the table should have a variable amplitude. Variable frequency is an added advantage.

Shock tables (used in the Schokbeton process), sometimes called drop tables, are suitable for consolidating low slump concrete. This process relies on lifting a relatively heavy table about $\frac{1}{8}$ to $\frac{3}{16}$ in. by using cams and then allowing it to drop against a solid stop. Frequencies are in the range of 150 to 260 drops per min. and the impacts generated compact the concrete effectively. The bottom surface of the unit will turn out very smooth and free from air voids. Sides may also be reasonably free of air voids if form is filled slowly during vibration. The forms are subject to relatively severe stresses.

Pneumatic or electric hand-held hammers may be applied directly to the outside surfaces of the mold or be brought to bear on the surface of the concrete. In addition to the ramming or tamping effect, there is a low frequency vibration (500 to 1000 vpm) which aids in consolidation. Care must be taken not to damage molds, particularly wooden ones.

DIVISION IV—MATERIALS

Section 1—Concrete Materials

4.1.2—Cement

Cements have different inherent color characteristics that could affect the desired concrete color. Although the volume of cement in a mix is small in comparison with the aggregate, it exerts a considerable influence on the color of the finished product due to its tremendous surface area per unit of weight.

Normal production variables such as changes in water content, curing cycles, temperatures, humidities, and exposure to climatic conditions at varying strength levels, all tend to cause greater color variations in a gray cement concrete in relation to concrete with white cement.

4.1.3—Facing Aggregates

The Architect-Engineer should approve or select the size, color and quality of aggregate to be used. This choice should be based on a visual inspection of a concrete sample prepared by the precast manufacturer, and on an assessment of certified test reports.

Selection of aggregates should be governed by the following:

(1) Aggregates should have proper durability, be free of staining or deleterious materials, non-reactive with cement and available in particle shapes required for good concrete (rounded rather than slivers).

(2) Final judgment of colors should be made with a concrete sample that has proper matrix and is finished similar to the planned production techniques. Some finishing processes change the appearance of aggregates. If small concrete samples are used to select the aggregate color, the Architect-Engineer should be aware that the general appearance of large areas after installation tends to be lighter than indicated by the trial samples.

(3) Aggregates with a dull appearance in a gray matrix may well appear brighter where the matrix is basically light.

(4) Weathering may influence newly crushed aggregates. When first crushed, many aggregates are bright, but will dull slightly with time. Similarly, some of the sparkle caused by acid etching or bushhammering may not survive more than a few weeks. This consideration is not important because time will compensate for these differences in uniformity. The Architect-Engineer should recognize that samples maintained indoors may not retain their exact appearance after exposure to weather for a few weeks.

uct. Natural gravels are inclined to shatter, leading to bond failure and loss of aggregate particles when bushhammered. Certain aggregates such as granite and quartz are difficult to bushhammer uniformly because they are very hard and they may fracture into rather than across the concrete surface. Aggregates such as marble, calcite, and limestone are softer and more suitable for bushhammered surfaces. The comb chisel is suitable only for use with softer aggregates. For sandblasting, hard aggregates such as quartz, granite, and siliceous gravels are generally used although some limestones are also suitable. (There is a tendency to round off edges of soft aggregates.) For grinding and polishing, the softer aggregates such as marble should be used. Granite and quartz are hard and increase the cost of grinding. When an acid-etched finish is used, or a solution of muriatic acid is used to wash an exposed aggregate surface to bring out its full color, only acid-resistant aggregates such as quartz or granite are recommended. Aggregates with a high calcium content such as limestones, dolomites, and marbles may discolor and dissolve in muriatic acid. Even a relatively mild acid solution may affect the color of some marbles or limestones and may cause crumbling or popping of the particles.

Fine aggregates have a major effect on the color of white and light colored concrete, and can be used to vary the particular color desired. Where the color depends mainly on the fine aggregates, gradation control is required, particularly where the color tone depends on the finer particles. Where fine aggregates (sand) are manufactured and bagged by sizes directly from the screening operations, uniformity in gradation can be maintained from one batch to the next. For fine aggregates in bulk, and subject to several rehandling processes, this is not feasible.

Uniform color appearance may be obtained by using crushed colored aggregate sand from the same material as the coarse aggregate. However, for reasons of workability, a percentage of natural sand is desirable in a concrete mix. If maximum whiteness is desired, a natural or manufactured white or light yellow sand should be used. Most naturally occurring sands lack the required whiteness, and the precaster usually must look to the various manufactured aggregates for the white base desired. Generally, these consist of crushed limestone, dolomite, calcite or quartzite sands.

The maximum size of coarse aggregate is usually controlled by (1) the dimensions of the unit to be cast, (2) clear distance between reinforcement, (3) clear distance between the reinforcement and the form, and (4) the desired finish.

Aggregate size should also be selected on the basis of the total area to be cast and the distance from which it is to be viewed. Aggregates exposed on the face of the precast unit may vary from ¼ in. up to stones and rubble 6 to 7 in. in diameter and larger. Larger aggregates are required on large areas for any degree of apparent relief. When surfaces are some distance from the main flow of traffic, large aggregate is required for a rough-textured look. A suggested visibility scale is given in Table D3.

Aggregate shape will affect appearance of exposed aggregate concrete, workability of the concrete and may affect color slightly. Cubical or rounded aggregates will give the best area coverage, and will contribute considerably to a good workable concrete mix.

Table D3. Suggested visibility scale

Aggregate size, in.	Distance at which texture is visible, ft
¼—½	20—30
½—1	30—75
1—2	75—125
2—3	125—175

Aggregates with a rough surface have better bonding properties than those with slick glassy surfaces. Bond is particularly important in cases where small size aggregates, ¼ in. and smaller, are used, as some of the aggregate pieces may be only half embedded in the cement matrix and may pull out of exposed aggregate finishes during finishing. Finishing procedures with these aggregates should be tested prior to use. With larger aggregate sizes, say ½ in. or larger, enough of each piece will be embedded to insure against loss of bond, even in the case of glassy, smooth aggregates.

Aggregate shape affects the tone of a surface after weathering. Rounded aggregates are largely self-cleaning while angular aggregates of rough texture tend to collect dirt; however, dirt pickup is generally confined to the matrix. For this reason, as well as architectural appearance, the area of exposed matrix between the pieces of stone should be minimized. It also may be advisable for the matrix to be darker than the aggregate for structures subjected to considerable atmospheric pollution.

Where aggregates are to be exposed, a specified gradation decombination of coarse and fine aggregates is preferred for exposed aggregate finishes, since its use results in a more concentrated and uniform surface exposure of the aggregate. Where surface textures are not as critical, the use of continuous graded fine and coarse aggregates, which contain proportions of particles of all sizes from the largest to the smallest, may be used. A gap-graded combination of fine and coarse aggregate will always have one or more standard particle sizes missing from the range of largest to smallest particle sizes. This leads to concentration of certain aggregate sizes in excess of standard gradation limits which are normally waived.

The use of closely-graded fine and coarse aggregates, in a gap-graded combination, results in less segregation and produces a more uniform finish. A better contrast between the exposed coarse aggregate particles and the matrix is obtained.

Gap gradings may include coarse aggregate in a short size range such as 1¼ to ¾ in., 1 to ½ in., ¾ to ½ in., ½ to ⅜ in., ⅜ to ¼ in. and others. Some common fine aggregate sizes are 30 to 50 mesh and 16 to 30 mesh. However, graded sand such as ASTM C 144 masonry sand, is better for its bleeding characteristics.

A suggested schedule of sizes to be used in exposed aggregate precast concrete and the tolerances in grading for four different aggregate sizes are shown in Table D4.

This schedule of sizes may not be recognized by some aggregate producers who either have established their own standards, or use sizes established by the terrazzo industry.

Table D4. Suggested size specifications for exposed aggregate

Sieve opening in.	Percent of indicated size aggregate passing			
	Size D 1⅜ x ⅞ in.	Size C ⅞ x ½ in.	Size B ½ x ¼ in.	Size A ¼ x 3/32 in.
1½	100			
1⅜	95–100			
1	30–60	100		
⅞	20–40	95–100		
⅝	0–10	30–50	100	
½		10–25	95–100	
⅜		0–10	40–70	100
¼			5–20	95–100
⅛			1–10	15–35
3/32				0–10

Coarse aggregate should be reasonably uniform in color. Light and dark coarse aggregates require caution in blending to provide uniformity in distribution and resulting colors within a single unit. With a small color difference between the light and the dark aggregates and a small variance in total amounts of each aggregate, the chances of uniformity are reasonably good, when proper mixes are used. Extreme color differences between aggregates and matrix will create uniformity problems.

The choice of aggregates is more critical with smooth white concrete. A light-colored aggregate is preferable to a dark aggregate to avoid the possibility of getting shaded or toned areas. Due to the greater difference in color between the white cement and aggregates, the white cement has less ability than gray cement to form an opaque film over the aggregates and prevent the aggregate color from showing through. Intensity of color, also, may be diminished when dirty aggregate is used from contaminated stockpiles. Thus, special consideration must be given to the selection of suitable aggregates to ensure against variations in color and grading.

4.1.5—Aggregates for Lightweight Concrete

Precasters using lightweight aggregates should be experienced in mixing and placing concrete mixes since their weight and shrinkage characteristics often require special attention in order to obtain a reasonable uniformity in appearance when exposed. The combination of normal weight face mix and a backup mix with lightweight aggregates may increase the possibility of bowing or warping. Before producing such a combination, pilot units, produced and stored under anticipated production conditions, are desirable to verify satisfactory performance.

4.1.6—Mixing Water

It is suggested that a chloride ion content greater than 400 ppm might be considered dangerous for the special conditions indicated, and it is recommended that levels well below this value be maintained, if practicable. Chloride ions contained in the aggregate and in admixtures should be considered in evaluating the acceptability of total chloride ion content of the mixing water. The chloride ion content can conveniently be determined on a sample of water extracted from a vigorously stirred mixture of moist aggregate, mixing water, and admixture combined in the same proportions to be used in the concrete.

4.1.7—Admixtures

Retarders will delay the time of set and finishing and will not usually fit into a high speed casting cycle. High dosages may cause tage should be taken of this property whenever possible.

The use of calcium chloride may cause non-uniformity in color of the concrete surface (darkening and mottling) and may disrupt the efficiency of surface retarders.

The use of fly ash in a concrete mixture will darken the color; at the same time it will improve workability to a considerable degree. In general, the curing of precast panels is usually not sufficient to allow full pozzolanic action to take place.

Usually, an admixture that has frozen in storage tanks or drums may be reconstituted after thawing without detrimental effect on the quality of the admixture. However, it is advisable to obtain the manufacturer's recommendation regarding this point.

All types of admixtures used should be materials of standard manufacture having well established records of tests to confirm their properties. Whenever practical, the use of admixtures in liquid form is highly desirable to obtain a more uniform distribution throughout the concrete mass within the time allotted to adequately and properly mix the concrete. Regardless of the form of the admixture, provision should be made for controlled and uniform introduction with other concrete components to ensure good distribution within the mix, in strict accordance with the admixture manufacturer's recommendations. Whenever more than one admixture is used in a concrete mix it shall be positively determined that each material will perform as required without affecting the performance of the other.

Coloring pigments of synthetic oxides are generally preferred because of better performance, but they may react chemically with other products, such as surface retarders or muriatic acid, and should be tested prior to use.

Variable amounts of a pigment, expressed as a percentage of the cement content by weight, produce various shades of color. High percentages of pigment reduce concrete strength because of the high percentage of fines introduced to the mix by the pigments. For these reasons, the amount of pigment should be controlled within the limits of strength and absorption requirements. Different shades of color can be secured by varying the amount of coloring material used or by mixing together two or more pigments. Pigments used with white cement will produce clearer shades than with gray cement.

Significant points to consider when pigments are used to obtain color are:

(1) Quality and quantity of the pigment.

(2) Fading characteristics of some pigments.

(3) Batching and mixing with the concrete.

(4) Quality (freedom from impurities) of the fine and coarse aggregates.

(5) Uniform quantities and gradation of fine materials (passing No. 50 sieve and including the cement) in the concrete mix.

(6) Careful attention to curing and uniform duplication of curing cycles.

(7) Type and color of cement.

(8) Constant water-cement ratio in the mix.

(9) Consideration of those factors that can contribute to efflorescence.

Chrome yellow, chrome green and lampblack should not be used because they will fade badly in concrete. Black colors of any kind readily fade to gray because of the thin layer of calcium carbonate that forms on all concrete surfaces when the leached cement hydration products undergo atmospheric carbonation. If the lightening of the color becomes too objectionable, the black can be restored by washing with dilute hydrochloric acid and rinsing thoroughly. Carbon black due to its extremely fine particle size has a long-range tendency to wash out of a concrete matrix. As the pigment dissipates the concrete substrate appears increasingly "faded." Water-dispersible carbon blacks are rarely used on a vertical exposure but are fairly popular for flat horizontal work. The addition of a non-modified carbon black will increase considerably the amount of air-entraining admixture necessary to provide an air content sufficient for proper resistance of the concrete to freezing and thawing. Water-dispersible phthalocyanine green should not be used where long-range permanence is a controlling consideration.

A blue pigment is generally unstable in the presence of the alkali in cement. All types should be avoided except cobalt blue and water-dispersible phthalocyanine blue, which should be used only after careful evaluation.

Titanium dioxide pigment in quantities of 1 to 3 percent is sometimes used to further intensify the whiteness of white concrete. However, it is doubtful that titanium dioxide would overcome the yellowing effect of yellow or brown sands when used in amounts that would not be detrimental to the strength and durability of the concrete. For these same reasons, titanium dioxide cannot be used instead of white cement to produce white concrete. In addition, the practice would not be economically feasible and uniform color would be extremely difficult to obtain.

The ease of obtaining uniformity in color is directly related to the ingredients supplying the color. Where color depends on the sand or the pigment, the requirements of several samples and full-scale mockups are essential to determine the range of variations similar to the actual project for a period of time, samples will have a darker shade when damp than when dry. Whenever possible, fine and coarse aggregates should be used to achieve color instead of pigments as this is the safest and the most economical way to obtain colors in a precast unit.

Architects can best specify the color they desire by referring to a swatch or color card. A cement color card is preferred but one published by a paint manufacturer is acceptable. An excellent color reference is the *Federal Color Standard 595 A,* published by the U.S. Government Printing Office.

Efflorescence deposited on the surface may mask the true color and give the appearance of fading even though the cement paste

Table D5. Shades of color for various pigments

Shades of color	Pigment	Remarks
Bright red to deep red	Natural red iron oxides	
	Synthetic red iron oxides	
Ivory, cream or buff, yellow	Natural yellow iron oxides	
	Synthetic yellow iron oxides	
	Nickel titanate yellow	Low tinting strength—use white cement
Brown	Natural brown iron oxides	
	Raw and burnt umber	
	Burnt sienna	
	Synthetic brown iron oxides	
Gray to black	Synthetic black iron oxide	
	Carbon black	Water dispersible
Green, olive, turquoise	Chromium oxide	
	Hydrated chromium oxide	Low tinting strength—use white cement
	Phthalocyanine green	Water-dispersible
Blue	Cobalt aluminate blue	Low tinting strength—use white cement
	Phthalocyanine blue	
	Cobalt oxide	High cost
White	Titanium dioxide	
	Zirconium orthosilicate	

itself has shown no change. In addition, weathering of the pigmented cement paste exposes more of the aggregate to view. If the color of the aggregate is in contrast to that of the pigment, a change in the overall color of the surface may be noted (see Table D5).

Section 2—Reinforcement and Hardware

4.2.1—Reinforcing Steel

Grades of reinforcing steel are determined by the structural design of the precast units. Grade 40 is generally used for nonstructural applications since units are designed as relatively crack-free sections, i.e., benefit of higher grade steel is not utilized.

The size of reinforcing bars is often governed by dimensions of element, required concrete cover over steel, and function of the element. In general, bar sizes should be kept reasonably small even where this will reduce the spacing of the bars. Smaller bars closely spaced will decrease the size of potential cracks and improve the distribution of temperature stresses. The use of additional reinforcing bars as compared with fewer heavier bars becomes more important in thinner concrete sections. Since the sum of potential cracks in concrete are more or less constant for a given set of conditions, the more cracks there are the smaller and less visible they will be.

Welded wire fabric reinforcement is commonly used as the main reinforcement and, if necessary, it is strengthened with reinforcing bars in ribs or where otherwise required.

Galvanized mesh or reinforcing steel is often considered for precast architectural concrete; however, it must be recognized that galvanizing cannot take the place of quality control in mix proportioning and steel placement. Galvanizing of steel is recommended when minimum cover requirements cannot be achieved. In these cases, the use of galvanizing should be specifically called for in the contract documents.

Wire fabric manufactured from galvanized wire is a stock item; therefore, the premium for using it is not high. The specification of hot-dipped galvanized reinforcing steel, other than wire mesh, may involve considerable expenditure.

The amount of zinc coating on wire fabric is rarely specified for galvanized steel wire fabric reinforcement. Galvanized wire can be produced with thicknesses of zinc coating ranging from about 0.30 oz. per sq. ft. to 2.0 oz. per sq. ft. for different grades and wire sizes.

Some precasters prefer galvanized wire fabric because rusting will be reduced during prolonged storage which is often required standardizing on two sizes only (heavy and light). The Architect-Engineer is advised to consult local precasters for preference in type and sizes of wire fabric.

When galvanized reinforcing steel is placed close to non-galvanized metal forms, the concrete may have a tendency to stick to the forms. This may also happen if non-galvanized reinforcement is used close to galvanized forms or form liners. Sticking may be prevented by passivating the surface of the galvanized steel reinforcement by using a chromate treatment. Chromate coating of galvanized surfaces can be readily done in most galvanizing plants and consists of either dipping the galvanized elements for 10 to 20 seconds in an aqueous solution having 150 gm per liter (20 ounces per gallon) of sodium dichromate and 5 to 10 cc per liter of H_2SO_4 (sp. gr. 1.84) or in a 5 percent solution of chromic acid (chromium trioxide solution). Spraying these solutions also may be used. The addition of chromic oxide (CrO_3) to the concrete mix (150 parts per million based on weight of mixing water or about 8 ounces of a 10 percent solution per cu. yd. of concrete) may also be effective in eliminating sticking and reflection of steel. *Precautions in handling of chromic oxide must be taken to avoid dermatitis.*

4.2.3—Connections and Inserts

Aluminum reacts with concrete and, in the presence of chloride ions, may also react electrolytically with steel causing cracking and/or spalling of the concrete. Aluminum electrical conduits present a special problem since stray electric current speeds up the adverse reaction. Dissimilar metals should not be placed in contact with each other unless experience has shown that no detrimental galvanic action will occur.

Hardware permanently protected with paint, galvanizing, or cadmium plating may require touch up prior to final installation of the element. Where connections requiring protection are not readily accessible for the application of zinc paint or metallizing after erection, they should be metallized, galvanized or cadmium plated prior to erection and connections bolted where possible. If welding is required as part of the field assembly, the welded area should be cleaned and touched up with zinc-rich paint. Development of special new resin paints for rust protection of hardware show promise of being effective.

Connections that are fully exposed so that they may be regularly inspected and maintained need only protective painting. Where connections are located inside a two-stage joint air seal, and condensation from cold bridges and/or humidity in the interior atmosphere is unlikely, painting is sufficient protection. Inserts, bolts, and other accessories should be electroplated, or made from noncorroding materials.

Protective coatings should be of such a quality and applied in such a manner that no embrittlement of a connection can occur, and that no loss of strength of the connection or loss of bond of reinforcement can occur which has not been anticipated and allowed for in the design.

The allowable load on an insert cast in an element should be determined by the results of laboratory controlled tests duplicating the loading condition in which the insert is used. In the absence of such a test, analysis of the connection is recommended to determine the limit of allowable service load.

Optimum economy in the manufacturing and incorporation of hardware items into precast units demands simplicity and repetition. Standardization of connections and inserts is an important aspect. It improves quality control in the plant and contributes to production economies. In general, heavier hardware should be used at lightly loaded conditions if it will eliminate a special piece mark and result in only slightly more material. This practice prevents the possibility of the smaller piece being used where the heavy one is required. As a safeguard against human error, changes in dimensions and materials in connection hardware should be in increments large enough for visual recognition.

4.2.4—Handling and Lifting Devices

Lifting devices of prestressing strand or wire aircraft cable properly sized and anchored are recommended whenever practical. Their use is generally limited to two-point pick-up since their projection from the concrete is subject to variation. Since the lifting devices are subject to dynamic loads, ductility of material should be part of the design requirements.

Lifting devices with exposed threads are safer to use than inserts because they can be visually inspected, but they do demand protection of the thread both during production and storage. Threaded inserts (coarse coil bolt) used for lifting should be protected during storage by plugging with wood, plastic, or cork. They should only be used with proper swivel plates and bolts and should be standardized within a specific job for depth of thread to minimize human errors in application. The use of a swivel plate assures that an angular pull will place the concrete insert primarily in tension.

In determining safe loads for lifting inserts, the inclination of the lifting force should be considered, although this may vary in case of separate handling operations. Consideration must also be may only be a fraction of its final design strength.

When permanent connection hardware is used for handling, it should be properly designed for such additional service without any danger of subsequent damage to such connections or their performance. Impact loads associated with handling and setting of precast units may double or, in extreme cases, triple the dead load used in the design of a connection. This depends on the methods and controls of hoisting and the vulnerability of the connection (or its anchorage) to impact loads. Where connections are designed for earthquake loads equal to or exceeding impact loads, the requirements for impact are automatically satisfied.

Section 3—Insulation

4.3.1—Materials

The insulating quality of a material will diminish if it absorbs moisture. For this reason, a material which exhibits no capillarity, or has suitable vapor barriers, should be selected. Some insulating materials may have high initial rates of absorption.

In sandwich panel construction, these materials are placed in direct contact with the plastic concrete faces, and overdrying of the fresh concrete may occur, preventing the cement from hydrating properly.

DIVISION V—PRODUCTION

Section 1—Project Samples

5.1.2—Mockups and Initial Production Approval

In assessing samples nearly everyone has a tendency to apply a little wishful thinking when trying to visualize how the entire unit —or even the entire facade—might look from viewing and touching a small 12-in. square sample. These samples may not reflect the relation between materials, finishes, shapes, casting techniques, mold types, orientation of exposed surfaces during casting, and consolidation procedures. This may lead to disappointments later when production is in progress.

Investing in mockups will remove uncertainties in the minds of Architect-Engineer and Owner alike or lead to modifications which may improve the appearance or reduce the overall cost of the project. These larger samples require considerable time in their manufacture, and should not be specified unless considerable lead-time is allowed for the entire project.

Section 2—Forms or Molds

5.2.1—Materials and Construction

Quality control need not concern itself with the number of forms or molds that will be required. This assessment is made by the production department; however, quality control frequently should discuss mold construction with production in order to develop an awareness of mold and product quality relative to cost considerations. Quality control personnel also should understand the basic mold concepts such as master mold and envelope mold.

The master mold concept is based on fabricating one master mold (with its appropriate additional tooling) which allows a maximum number of casts per project. Units cast in this mold need not be identical provided the changes in the units can be accomplished as pre-engineered mold modifications.

Modifications should be achieved with a minimum of idle production time and without jeopardizing the usefulness or quality of the original mold. An illustration is provided in Fig. D1.

A blockout is a type of modification that is relatively easy to accomplish. Bulkheads may be used to modify the precast unit. Such modifications may be used to provide clearance for columns in specific locations, or for precast units which are identical except for window openings. Simple modifications are also accomplished by the use of bulkheads for units which comprise only a part of the master mold.

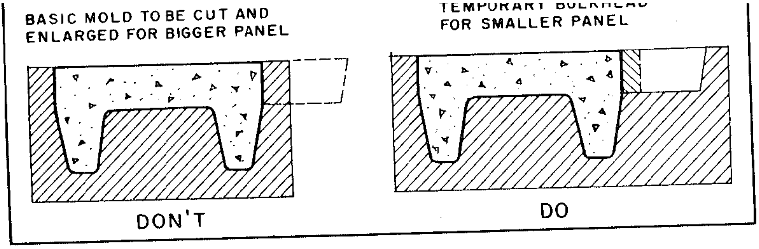
BASIC MOLD TO BE CUT AND ENLARGED FOR BIGGER PANEL
TEMPORARY BULKHEAD FOR SMALLER PANEL
DON'T
DO

Fig. D1. Master mold concept

The complete envelope mold is a box mold where all sides remain in place during the entire casting and stripping cycle. Such molds have good economy and quality potential because they are usually simple to build and maintain, with enough strength to withstand concrete pressure during and after consolidation. Fig. D2 shows a complete envelope mold, while Fig. D3 illustrates the more conventional mold with removable side and end bulkheads.

A modification of the complete envelope which will accommodate precast units without drafts along one or more edges is illustrated in Fig. D4.

This mold provides good corner details, but loose side rails are

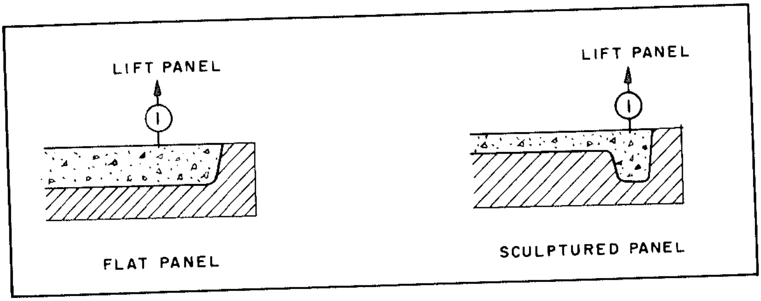

Fig. D2. Envelope mold

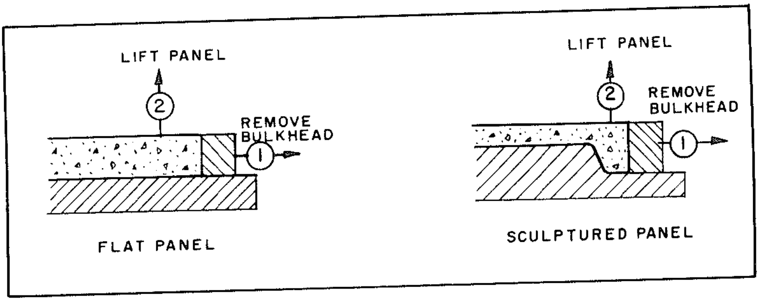

Fig. D3. Conventional mold

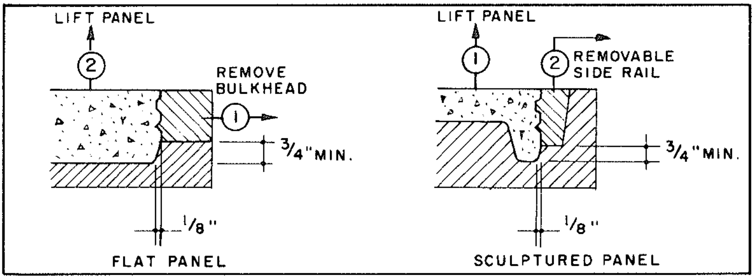

Fig. D4. Modified envelope mold

stripped with the unit. The side rails allow 90-deg. returns or returns with negative draft, and are fairly easy to reassemble, eliminating the need for daily measuring and aligning. Such modified envelope molds, however desirable for quality and daily cost savings, cannot justify their initial cost unless reasonable repetition exists.

Forms or molds should be designed to prevent damage to the concrete from:

(1) Restraint as the concrete shrinks. Note that in large molds, dimensions exceeding 20 ft., allowance for shrinkage and thermal expansion or contraction should be considered in the design of the master pattern and/or the mold.

(2) The stripping operation when the unit is lifted from the mold.

(3) Dimensional changes due to pretensioning of a prestressed panel—binding and pinching caused by elastic shortening of the member when the prestressing force is applied. It may be desirable to design the mold with sufficient strength to be used as a support for the prestressing anchors.

Whenever possible molds should have sufficient draft to facilitate stripping with a minimum of mold breakdown. The minimum drafts generally accepted are shown in Fig. D5. Generally, the minimum draft which will enable a unit to be stripped easily from a mold is 1 in. in 1 ft. (1:12). This draft should be increased for narrower sections or delicate units as the suction between the unit and the mold then becomes a major factor in both design and stripping. The draft should be increased to 1:6 for screen units with many openings, or for ribbed panels. Drafts for ribbed panels should be related to the depth and spacing of the ribs.

The drafts selected for finish consideration will vary due to shapes and techniques proposed for production. Vertical sides or reverse (negative) drafts will create entrapped air voids which, if exposed, may be objectionable.

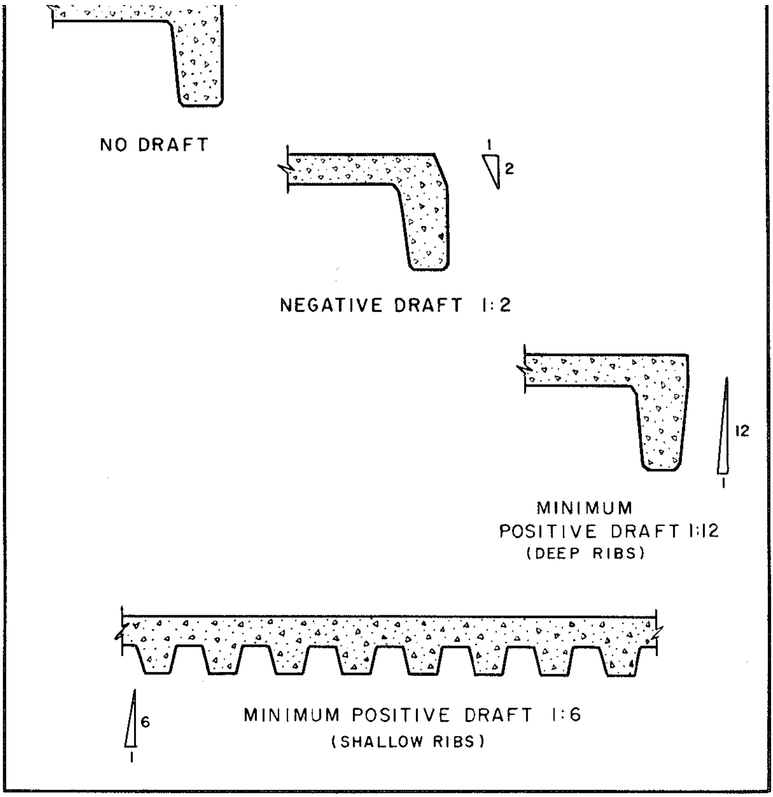

Fig. D5. Drafts for ribbed panels

Section 3—Reinforcement

5.3.1—General

The belief that prestressing will reduce or control bowing or warping is a misconception. Unless tendons are located accurately, concentric with the cross section, and securely maintained in that location during casting and curing, prestressing may actually increase the occurrence of bowing. If panels are prestressed, strand ends and anchorages must be recessed and packed or otherwise carefully protected to avoid corrosion, and possible rust spots which may mar the surface after years of service.

5.3.2—Fabrication

Tack welding, unless made in conformance with AWS D 12.1, may produce crystallization (embrittlement or metallurgical notch) of the reinforcing steel in the area of the tack weld. Tack welding seems to be particularly detrimental to ductility (impact resistance) and fatigue resistance, and, to a lesser extent, to static yield strength and ultimate strength. Where a small bar is tack welded to a larger bar, the detrimental "notch" effect is exaggerated in the large bar. Fast cooling under cold weather conditions is likely to aggravate these effects.

5.3.3—Installation

Concrete cover on the reinforcing steel should be related to the following:

(1) Structural or nonstructural use of panel.
(2) Maximum aggregate size (cover shall be greater than maximum aggregate size).
(3) The means of securing the steel in a controlled position, and maintaining this control during placement of concrete.
(4) Accessibility for placement of concrete, and the proportioning of the concrete mix relative to the structural environment.
(5) The type of finish treatment of the concrete surface.
(6) The environment of the concrete surface: interior or exposed to weather, ocean atmosphere, or aggressive industrial fumes.
(7) Fire code requirements.

Reinforcing steel in some finishes may show up as shadow lines depending on mix, vibration of reinforcement, placing, etc. In order to modify manufacturing procedures to eliminate shadow lines, it is necessary to understand the possible causes.

During vibration of the concrete, the agitation is much more vigorous near the surface of the form under the steel. The agitation tends to cause a greater concentration of cement and fine particles of the aggregate at the form interface under the steel. These fines scatter light better and tend to give the area a light color. This is, therefore, only a "skin deep" change in the concrete. The concrete beneath the steel surface at the ghosting is the same as the balance of the concrete. This ghosting problem may be aggravated by excess form-release agent being folded into the surface of the concrete during vibration. This folding motion will be greater under mesh wires or reinforcing bars.

Steel reflection may be more likely to occur when minimum cover is used over the steel and a rigid steel cage is used. The cage will vibrate as an assembly in phase (resonates) during the intense vibration used to compact the low-slump concrete of precast concrete. Welded wire fabric or tack welding of steel will stiffen the steel cage and is more likely to produce reflection. Tied steel assemblies should not have this problem. In some cases, the light and reversed. This type of shadowing may be related to lack of compaction in areas where steel concentrations prevented full vibration of the covering concrete.

The following are approaches to alleviate shadowing: Cages should be tied and not tack welded to reduce rigidity. Galvanized steel should be treated with a chromate wash or chromic oxide added to mixing water. To avoid settlement of the steel reinforcement with consequent loss of steel cover, it would be expedient to use chairs or support steel from above. If external vibration is used, steel support should be isolated from mold to prevent vibrations being transmitted into the cage. A 2-in. layer of low slump concrete (slump as low as can be reasonably compacted) should be placed and compacted—if internal vibration is used, extra care must be taken to avoid vibration of the steel caused by touching the cage with the vibrator. If chairs are not used, the 2-in. layer of concrete should be allowed to set (adequate bond must be obtained between concretes) so that the initial lift is capable of keeping the steel grid from settling. When vibrating the top layer of concrete, care must again be taken to avoid vibrating the steel.

If shadowing does occur, sandblasting with the smallest available gun and nozzle and using fine grit can reduce the reinforcement outline to a reasonably uniform tone. However, portions of the surface immediately over the reinforcement may be less dense than areas away from the reinforcement making it extremely difficult not to over-erode the surface over the reinforcing steel.

Section 4—Hardware

5.4.1—Installation

The design of lifting devices, including checking of stresses in units during handling, is normally the responsibility of the precaster. Location of lifting hooks and inserts should be determined carefully to avoid excessive stresses in the units during handling, and they should have an adequate safety factor. The proper location of lifting points relative to the center of gravity of the unit will insure that no overstressing or failure occurs during erection. Also, during stripping of horizontally cast units, lifting points should be balanced over the center of gravity or other techniques used so that the unit can be lifted directly from the form.

Panels with openings should be carefully checked for erection stresses. It is desirable that all lift inserts be placed above and/or below openings, i.e., in a section of maximum strength. The center of gravity should be computed and lift points located so as to place the center of the crane hook directly above the center of gravity of the unit. Thus, the bottom of the panel will hang level during erection.

Conduits, pipes, wiring and other appurtenances should be located where they do not reduce structural strength below requirements. Built-in fixtures should be placed where they do not affect the position of the main reinforcement or the placing of concrete. Dissimilar metals should not be placed in contact with each other to prevent detrimental galvanic action.

Weld plates should be located so that they efficiently support the panel. Placement at panel corners, where plate anchors are difficult to embed properly or tie to panel reinforcement, should be avoided.

Section 5—Concrete Casting

5.5.1—Mix Proportioning

Concrete mixes are usually divided into three groups, namely, facing, backup, and standard mixes. Facing mixes are usually composed of special decorative aggregates, and are frequently made with white or buff cement, where exposed aggregate surface finishes are desired. Backup mixes are usually composed of more economical local aggregates and gray cement and are used to reduce material costs in large units employing face mixes. In precast units of complicated shapes and deep, narrow sections, the facing mix may be used throughout the member if procedures for separating the facing and backup mixes become too cumbersome. Standard concrete mixes may occasionally be used where exposed aggregate or other special finishes are not required, and where the size and distribution of aggregate are not critical; standard mixes may also be used as backup mixes if the physical characteristics are similar to the facing concrete.

A curve should be established showing the relation between water-cement ratio (or cement content) and compressive strength. The curve should be based on at least three points representing batches which produce strengths above and below that required. Each point should represent the average of at least two specimens tested at 28 days or the earlier age designated. Trial mixes should be proportioned to produce a slump within 1 in. of the maximum permitted, and for air-entrained concrete, the maximum allowable air content. The temperature of concrete used in trial batches should be reported.

Mix designs and concrete proportions may be selected on the basis of established records for the concrete production facility. The better the control, as measured by the coefficient of variation or standard deviation, the more economical the selected mix may be-can influence concrete strength. Concrete for which *all* specimens can be expected to show strengths above the specified minimum strength is generally impractical, and evaluation of strength tests should recognize this fact.

Concrete for background tests to determine standard deviation is considered to have been "similar" to that required if it was made with the same general types of ingredients under no more restrictive conditions of control over material quality and production methods than will exist on the proposed work, and if its specified strength did not deviate more than 1000 psi from the required strength. A change in the type of concrete or a major increase in the strength level may increase the standard deviation.

A design strength for concrete should be determined by the Architect-Engineer, based upon in-service requirements, not forgetting production and erection considerations. Except for load-bearing units, stresses on units are higher during fabrication and erection than those anticipated in the structural design. Production requirements for early stripping of units or stress transfer and subsequent rapid reuse of forms demand high levels of early compressive strength. The minimum transportation and erection strength levels will depend on shape of the unit, handling, shipping and erection techniques and on schedule which will normally result in high 28-day strengths.

The concept of "strength ceiling" may be useful in indicating the maximum compressive strength attainable in concrete made with a given aggregate using a reasonable quantity of cement. A mix is near its strength ceiling when similar mixes containing the same aggregates and with higher cement contents have only slightly higher strengths. It is the point of diminishing returns, beyond which an increase in cement content does not produce a commensurate increase in strength. Strength ceiling is influenced predominantly by the coarse aggregate. For example, the strength ceiling can be increased appreciably by reducing the maximum size of the coarse aggregate for most lightweight aggregates. This effect is more apparent for the weaker and more friable aggregates.

Mix design factors which influence appearance are selection and proportioning of fine and coarse aggregate, color of cement and use of pigments.

Selection of fine and coarse aggregate affects both density and appearance. The quality of the aggregate does not necessarily provide good mix design, but it does relate to quality of concrete as evidenced by its durability. If the aggregate material is not durable, deterioration can be expected in areas where the concrete is in contact with corrosive atmospheres, salts, excessive moisture, and/or severe temperature changes.

Proportioning of fine and coarse aggregate is of importance to workability of the mix and, thus, to final appearance.

Required workability is related to the shape of the precast unit and the method of consolidation. Positive methods of consolidation using mechanical equipment require less fines for workability. The lower the percentages of fines, the lower the specific surface area of the aggregates and the lower the water and cement requirements of the mix, which leads to higher quality potential of the concrete. However, very low fines content mixes may bleed excessively and require a high water content for workability.

For uniform color with an as-cast finish, a mix should be rich in cement, with a high fine sand content and continuously graded coarse aggregate. The quantity of coarse aggregate normally found in a good structural mix is adequate (a minimum of 1800 lbs. per cu. yd.). Although a high proportion of sand is recommended to reduce color variations, a low proportion of sand is required to inhibit air voids. It is necessary, therefore, to decide which blemish is more important to eliminate for a particular purpose. The aim generally should be to produce uniformity of color and avoid segregation. If suitable form materials, release agents, and placing techniques are used, air voids on a surface can be almost eliminated or at least reduced in size and number to an acceptable level.

For a very light exposed aggregate finish, the concrete mix, like that used with an as-cast surface, can be a uniformly graded mix as the color is largely determined by the cement. However, there is more secondary influence from the fine aggregate in this type of finish.

For a light exposed aggregate finish, conventional mix design methods can be used, except that at least 10 percent more coarse aggregate is recommended.

For a medium to heavy exposed aggregate finish, the coarse aggregate is required to be uniformly distributed over the surface to produce an acceptable result. The concrete mix should be designed with a higher than normal coarse aggregate factor to minimize the probability of uneven distribution (a minimum of 2000 lbs. per cu. yd.). While a concrete sand gradation can usually be used, it is advantageous in some cases to use a masonry or industrial sand for the fine aggregate where most of the particles pass a No. 8 sieve.

Gap-grading is usually necessary for a medium to heavy exposed aggregate finish and a careful gradation of both coarse and fine aggregate is important. The maximum size of aggregate in gap-graded mixes should be 1 in. since mixes with larger sizes are exmove from their original position even with heavy vibrator effort and they are more prone to segregate.

While gap-grading is an established and well proven practice, it should not be carried to extremes. This may cause separation of the paste and aggregates and thus create uniformity problems, especially where the mix is not deposited directly in its ultimate location. The amount of fines, cement and water should be minimized to ensure that shrinkage remains within acceptable limits and that surface absorption will be low enough to maintain good weathering qualities. The durability of the concrete would normally not be affected by any degree of gap-grading as long as proper concrete cover is maintained over the reinforcement. The degree of gap-grading should be based on appearance, but also related to production considerations and the weathering qualities desired for the specific exposure of the concrete. Gap-grading can produce a smooth surface free from air voids, but it usually also tends to give color variations and aggregate transparency. (See Appendix D, Article 5.6.1 for a discussion on aggregate transparency.)

For most tooled surface finishes, medium and high coarse aggregate contents are advantageous, although gap-grading is generally not required.

For adequate consolidation of gap-graded concrete, the desirable range of matrix (air, water, cement and sand) is about 45 to 51 percent by volume depending on the angularity of the one-size coarse aggregate. Rounded aggregate, such as gravel, requires about 45 to 48 percent matrix, while crushed limestone requires slightly higher values, such as 48 to 51 percent. Most continuously graded concretes have matrix percentages of 55 or more.

For exposed aggregate concrete, the proportion of cement to fine aggregate by volume used in facing mixes should be at least 1:3 but not greater than 1:1. A reasonable balance should be established between a minimum cement content for strength requirements and a maximum cement content to diminish its negative qualities, such as shrinkage, tendency to crazing and a hardness lower than that of the aggregates. With mixes leaner than 1 part cement to 3 parts sand, there is some danger of pieces of coarse aggregate being dislodged during handling. The ratio of volume of fine aggregate to coarse aggregate for facing mixes is about 1:2½ or 1:3. This is due to the need for a high concentration of coarse aggregate to achieve a uniformly textured finish. Backup mixes more nearly approach 1:1½.

The percentage of sand should be chosen carefully. A wrong choice (too low a percentage, for example) may result in segregation or honeycombing due to an excess of coarse aggregate. An excess of sand results in a less desirable architectural appearance. Concrete with a low density and high water requirement can also result from too much sand. Sand is usually 25 to 35 percent by volume of the total aggregate. The lower percentage is used with rounded aggregates and the higher with crushed material. For a smooth surface, a somewhat higher percentage of sand to total aggregate may be used than for exposed aggregate surfaces but both use a lower sand content than for continuously graded mixes. The sand content depends on the cement content, type of aggregate, and workability. Since low-slump gap-graded mixes use a lower percentage of sand, producing harsh mixes, air entrainment is a standard requirement for workability with added durability as a bonus.

A high water-cement ratio increases shrinkage, permeability, and the possibility of segregation and excessive bleeding and decreases strength and durability. Variations in water-cement ratio

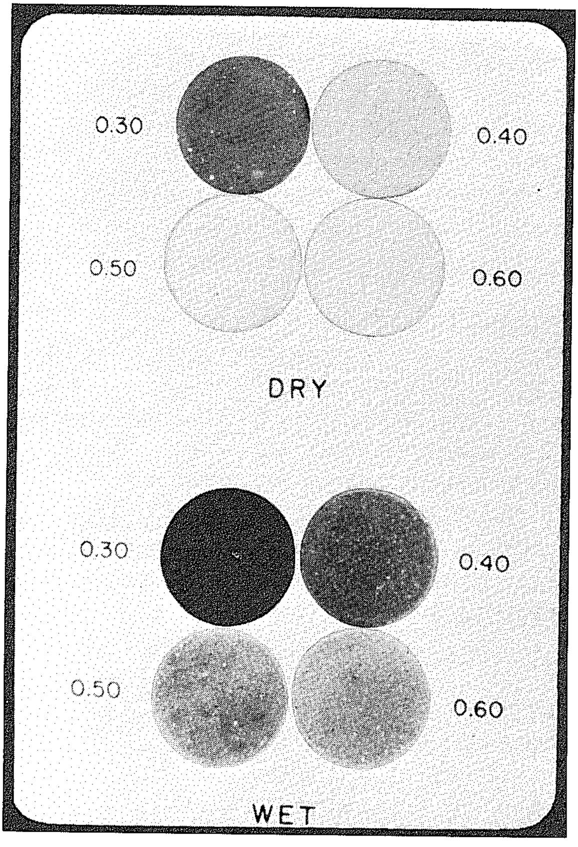

Fig. D6. Comparison of the color of mature gray cement pastes (W/C ratios from 0.30 to 0.60)

ratios produce lighter and lower ratios darker concrete (see Fig. D6). Batch-to-batch variations in water content, therefore, are potential causes of discoloration. Practical methods for water reduction and increased workability of mixes include water-reducing admixtures, air-entraining admixtures and provision of the optimum equipment for compacting concrete in the various sections and products.

It is important to realize that even with the same proportions, the slump varies with different materials. Concrete mixtures using natural sand and gravel aggregates require less water for workability than do concrete mixes using crushed sand and coarse aggregate; therefore, they will have a greater slump with the same amount of water.

In determining the proper consistency for lightweight concrete, it should be noted that the lighter weight of the fresh concrete produces lower slumps than with normal weight concrete of the same workability. A slump of about 3 in. imparts sufficient workability and also maintains cohesiveness and "body," thereby preventing the lighter coarse particles from working up through the mortar to the surface. (This is the reverse of normal weight concretes where segregation results in an excess of mortar at the surface.) A slump in excess of 4 in. will cause unnecessary finishing delays.

5.5.2—Batching and Mixing

Varying the length of mixing from batch to batch may cause different degrees of dispersion of cement or coloring pigment, if used, and, therefore, different shades of color. This is particularly important when using white cement with or without color pigments and when colors of sand and cement differ. Both undermixing and overmixing should be avoided. Undermixing will result in concrete of variable consistency and color and low strength; excessive overmixing results in loss of air in air-entrained mixes, grinding of aggregates, elevated mix temperatures, and loss of workability requiring additional water.

5.5.3—Placing

Discoloration may be caused by excessive use or uneven application of the release agent. Release agents of high viscosity or which are applied in thick applications tend to hold air and water bubbles and should be avoided. Any excess amount of release agent should be wiped off with a clean lint-free cloth and care should be taken to prevent embedded reinforcement and hardware from becoming contaminated by the release agent. The amount of coating applied will depend normally on the type of material being used and on the form surface condition. Generally, the thinner the coating is applied, the better the surface finish, but the film must be a complete one. Great care should be taken to see that the equipment used for applying the coating is clean.

In general, the form oils used for precast concrete are lacquer or emulsified stearates with a paraffinic or naphthenic crude base. Of the oils, the paraffinic type is preferred; it tends to be lighter in color although heavier in body. One non-proprietary material for experimentation is a 50–50 mixture of stearic acid and benzene

For steel forms, release agents should contain a rust inhibitor and be free of water. Rough surfaces on steel forms may be conditioned against sticking by rubbing on a liquid solution of paraffin in kerosene, or the forms may be cleaned and oiled with a non-drying oil, and exposed to sunlight for a day or two.

To reduce color changes, a suitable release agent should be applied for the first and all subsequent uses of glass fiber reinforced plastic forms or plastic form liners. An oil-phased emulsion or high quality household wax are preferable. Unsaturated oils, ketones, esters, acids, toluol, toluenes, xylenes, or halogenated solvents should be checked for compatibility with the plastic materials.

Concrete forms, although ground, smoothed, and polished, will require a release agent. Light colored petroleum oils or oil emulsions have been used successfully. The concrete surfaces may be coated with one or two coats of epoxy resin and then waxed. A saponifiable oil should not be used as a release agent.

Most rubber mattings do not require release agents when thoroughly cleaned and moistened with water before concrete is placed. Some users prefer to coat the rubber with a thin film of castor oil, vegetable oils, lanolin, or water-emulsion wax. Mineral oils, oil-solvent based release agents, or paraffin wax should not be used as these will soften the rubber. The rubber supplier's recommendations should be carefully followed.

Plastic foam forms are generally lightly sprayed with castor oil, petroleum jelly thinned with kerosene, or paraffin oil.

After plaster waste molds are thoroughly dry, two coats of white shellac can be applied to the mold surface to make it waterproof and non-absorbent. Before placing concrete, the mold should be lightly greased with a non-staining soft yellow cup grease or cup grease thinned to a point where it can be applied with a brush by addition of a mixture of crystallized stearic acid and kerosene.

5.5.4—Consolidation

The frequency and amplitude of vibrating forms and vibrating tables equipped with external vibrators should be determined at amplitudes are not only wasteful of vibrator power but can, in some cases, cause the concrete to roll and tumble so that it does not consolidate properly.

Moving one's hand over the form will locate areas of very strong or weak vibration (high or low amplitude) or "dead spots" where virtually no vibration exists. The vibrating reed tachometer can provide slightly more reliable information; the difference in oscillation of the reed at various points gives a rough indication of the difference in amplitude. The amplitude at various locations on forms vibrated externally are best determined by the use of a vibrograph. The frequency and wave form are also generally provided. Another simple method is to spread a thin layer of dry sand on a vibrating table and observe the movement of the sand while the table is vibrating.

With rapid penetration of an internal vibrator and slow withdrawal, the entrapped air can escape through the uncompacted layer much faster. The vibrator should be held stationary for about 5 to 10 seconds (depending on the mix and the force exerted by the particular vibrator used) until the top of the concrete is covered with a thin film of glistening mortar, and the entrapped air bubbles are no longer rising to the surface. The vibrator should then be withdrawn slowly, at the rate of about 2 in. per second so that the entrapped air bubbles have enough time to rise. The vibrator head should be held near the surface momentarily until the air bubbles have stopped escaping from the surface. The concrete should move back into the space vacated by the vibrator. For dry mixes where the hole does not close during withdrawal, sometimes reinserting the vibrator a few inches away will solve the problem. If this procedure is not effective, the mix or vibrator should be changed.

The radius of action is approximately four to five times the diameter of the vibrator head and varies depending on the slump and aggregate gradation. To reduce air voids in concrete surfaces, the distance between internal vibrator insertions should be reduced, and the time at each insertion increased.

Revibration of preceding layers of concrete is beneficial as long as the concrete responds to vibration and again becomes plastic. As long as an immersion type vibrator will sink due to its own weight, revibration will be beneficial.

When vibrating thin slabs, the internal vibrator tube should be held at an angle or even horizontally in order for the vibrator to operate in a fully embedded position. The horizontal position is probably more effective than the vertical position, because the vibratory waves at right angles to the vibrator are now in the same direction as gravity. Nevertheless, vertical insertions are preferred for most work, because it is simpler and provides more systematic coverage of the lift.

In general, internal vibration should be carried out with the vibrator completely immersed in the concrete. If the vibrator protrudes through the top surface, some of the energy normally transmitted into the concrete will be lost. Additionally, the large force exerted at the surface causes a violent turbulence there. This results in segregation, with a weak mortar layer forming on the surface. Vibrators may also get overheated when they do not have the full benefit of the concrete's cooling effect.

The method of attaching form vibrators may be designed either for rapid assembly and disassembly or for more permanent installation. Attaching external vibrators directly to the form is generally unsatisfactory because the skin may flutter or develop a diaphragm action. This movement causes the vibrational force to be highly localized, and sometimes results in early failure of the form. Vibrators should be mounted on stiffeners, e.g., open channels or box channels, or manufacturer's recommended mounting instrucions should be followed.

Vibrators may be attached directly to concrete molds by casting 6-in. wide flange beams full length or a grid of three 1½-in. diameter pipes in mold. Flush caps are first welded on each end of the beam or pipe, then vibrator brackets are welded to caps. The vibrator axis should be perpendicular to the stiffener. (Sometimes a 90-deg. turn to the parallel axis position produces more uniform vibrations.) Another approach is to cast a track into the concrete mold. The track can be cast in so that the opening is flush with the side or bottom of the form, or it can be welded to the outside. This then allows the vibrators to be moved to any point along the length of the form or at any interval as the casting progresses.

The rigidity of mounting of rotary electric units can readily be determined by measuring the amperage draw. If it exceeds the nameplate rating, the support is not strong enough. It will then be necessary to adjust the eccentricities to produce less centrifugal force or to stiffen the form. Another possibility might be to increase the number of vibrators on the form. Air vibrators can be evaluated as to mount rigidity by measuring their speed; if speed drops below 7000 revolutions per min., then the mount must be strengthened; also observing movement of the form gives an indication of the rigidity.

If the vibrator performs erratically when first operated, it will usually be due to:

(1) Loose bolts or key attachments.

(2) Torn weld seams on the form or stiffener.

(4) Low voltage input or air input.
(5) Resonance influence of the form or other vibrators.
(6) Rotation in the wrong direction.

In most cases these problems can be corrected by tightening the bolts, the taper pin, or by changing the direction of rotation. Turning the vibrator 90 deg. may also help. If these steps do not remedy the situation the form requires additional reinforcing or stiffening.

The recommended approach to spacing form vibrators is to start with a spacing, generally in the range of 4 to 8 ft. or spacings based on previous experience. If this pattern does not produce adequate and uniform vibration, the vibrators should be relocated as necessary until proper results are obtained. To achieve the optimum spacing requires knowledge of the distribution of frequency and amplitude over the form, and an understanding of the workability and compactibility of the mix.

When the form consists of several sections, at least one vibrator should normally be placed on each form section. Where a number of sections facing each other are used, e.g., for a long concrete beam, it will often be sufficient to mount a form vibrator on only one of two opposing form sections, depending on thickness of the unit. Location halfway up the height of the form is common. However, the exact vertical position is not of importance for vibration results. It is often advantageous if all the external vibrators on a vertical form section rotate in the same direction. On horizontal forms or vibrating tables opposite directions of rotation should be chosen.

It is desirable to be able to vary the frequency and amplitude of the vibrators. To eliminate nodes it may be necessary to use a combination of high and low frequency or have the operator run the vibrator through full frequency range. On electric or hydraulic driven external vibrators, amplitudes can be adjusted to different fixed values quite readily. On air-driven external vibrators, the frequency can be adjusted by varying the air pressure with a simple throttling device while the amplitude can be changed by replacing the eccentric weight.

It is generally desirable to avoid high amplitudes since they are hard on the forms. In order to get enough vibrational force, it is necessary to use rather high frequencies. External vibrators on wood forms should be spaced closer than on steel forms because wood tends to dampen the effect of high frequencies.

Form vibrators tend to draw mortar to the form, and when used in combination with internal vibrators have proved effective in reducing the size and number of air voids on the surface.

The noise level is directly proportional to frequency and for high frequency form vibration is often very high, primarily due to the oscillations of the form, particularly steel. Wood, fiberglass and concrete molds are much quieter. The following are methods to reduce noise levels:

1. Tighten all loose elements.
2. Use isolation at ground.
3. Add foam materials under structure to deaden sound.
4. Muffle air vibrators.
5. Avoid resonance.
6. Solidly connect all structural members in contact with each other that are not welded or bolted.

The vibration force required to achieve proper consolidation on wooden casting decks is approximately one-quarter more than on steel tables. This is mainly due to the poor vibration transmitting characteristics of wood. Care must be taken to obtain the proper distribution of vibration. Vibrators should be mounted on 1-in. thick mounting plates between two of the support members and preferably at the junction of the transverse and longitudinal support members.

Tables up to 14 ft. wide are best energized by mounting external vibrators on the lower flange of the longitudinal structural supporting members (I-beams, wide flange beams or heavy channels), and/or on a capping plate at the end of each structural member, depending on the table length. It is important that all the vibrating beams under each form are horizontal and at exactly the same height, to ensure that both the vibrating beams and the form are loaded as equally as possible. Vibrators should be mounted with their axis horizontal. If mounting of the external vibrator to the web portion of the structural members (within 10 ft. of the ends) is necessary, due to limited space beneath the undercarriage, the addition of transverse reinforcing members at the vibrator's location is necessary. If transverse reinforcing is pipe or tubing rather than angle or channel, proper distribution of vibration waves will occur (nodes reduced). This will also eliminate the swinging action of the support member caused by the vibration forces reacting against the weak web section of the supporting member which could cause form damage.

If the vibrating table is equipped with a vibrating element containing only one eccentricity, a circular vibrational motion may be obtained which imparts an undesirable rotational movement to the concrete. This may be prevented by mounting two vibrators side by side in such a manner that their shafts rotate in opposite directions. This neutralizes the horizontal component of vibration, so the table is subjected to a simple harmonic motion in the vertical direction only. Very high amplitudes may be obtained in this beams should be adjusted to rotate in such opposite directions that horizontal movement of the form being vibrated is prevented.

Some general rules for vibrator placement vs. length of form are:

(1) Long, narrow members up to 18 in. high:
(a) Up to 10 ft. long—one unit at one end.
(b) 10 to 18 ft. long—one unit at each end.
(c) 25 to 35 ft. long—add third vibrator on side of frame at middle or under if enough head room.
(2) Square or rectangular members (8 to 12 ft. wide and up to 20 ft. long with greatest height 24 in.—use four units mounted off each corner 25 percent of length on that side of frame.
(3) High, narrow profiles should be internally vibrated since too much energy is lost if steel undercarriage is vibrated.

5.5.5—Curing

Methods of curing fall into three categories:

(1) Supply of additional moisture. Such methods include sprinkling or covering with moist burlap, cotton mats or other moisture-retaining fabrics. Continuous sprinkling with water or use of fog sprays are excellent methods. An adequate supply of water and careful supervision are required to achieve proper application of water and to prevent damage to the surface. Curing water should be nonstaining and uniformly applied to achieve uniformity of color. Extreme care should be taken to insure that the wet covering selected does not stain or discolor the concrete surface. If retarding agents are to be used, water curing should be delayed until the finishing has been completed.

(2) Prevention of moisture loss. Such methods include using moisture-retaining covers or applying membrane curing compound conforming to ASTM C 309. Waterproof paper and plastic sheets are effective means of curing but are generally not used because condensation and dripping will occur where covers have only partial contact with the concrete. This will cause color differences in the various areas. Plastic sheeting may be used to assist the crucial initial curing of surfaces that will not be exposed to view.

In the use of membrane curing compound, the following precautions should be observed:

(a) The membrane coating should cover the entire surface to be cured with a uniform film which will remain in place without gaps or omissions until the full design strength of the concrete is reached. To detect omissions, it is recommended the membrane curing compound should contain pigments or fugitive dyes.

(b) Membrane curing compound should be applied at a rate of coverage not in excess of the manufacturer's recommendations and generally not in excess of 400 to 450 sq. ft. per gallon.

(c) Membrane curing compound should be applied to top surfaces as soon after casting as the surface water sheen disappears.

Curing compounds should not be used, except perhaps on the backs of panels before the removal of forms or where the surface is later removed by sandblasting or tooling, because of their tendency to discolor or stain. Some curing compounds may interfere with adhesion of repairs or surface coverings such as paints, fabrics, insulation materials or other specified protective coatings. Manufacturers should be consulted as to the effect that their compound has in these respects. In addition, membrane curing compounds should not be used in areas where joint sealants may be applied.

(3) Acceleration of strength gain by supplying heat with or without additional moisture. Accelerated curing should not be used for architectural precast concrete units where this may in any way endanger finish appearance or have an adverse effect on mold qualities. For an accelerated curing method two principal requisites are:

(a) Controlled application of heat for proper hydration of cement and to avoid subjecting the elements to thermal shocks by sudden ambient temperature changes.

(b) Supplying or retaining moisture in the fresh concrete to facilitate proper hydration of the cement.

The heat source may be one of the following or a combination of them:

(a) Live steam applied within a suitable enclosure around the products.

(b) Radiant heat applied to the molds by means of pipes circulating steam, hot oil or hot water.

(c) Electric blankets or heating elements outside the products.

Curing with live steam should be done within a suitable enclosure to retain the live steam to minimize moisture and heat losses. Steam jets should be positioned so that steam not discharge directly on the concrete, forms or test cylinders.

The cycle of heat application should conform to the following:

(a) After placing, consolidation and finishing, the concrete should be allowed to attain its initial set before heat is applied; otherwise the elevated temperature may have a detrimental effect on the long-term strength of the concrete. Enough heat should be applied to the form and its surrounding atmosphere to maintain the concrete at not less than 50 F. A period of 2 to 4 hrs., depending on climatic conditions, type and brand of cement and admixtures, temperature of the mix and water-cement ratio is required for the concrete to attain its initial set. Delay periods in excess of 10 hrs. may result in loss of effectiveness of heat curing.

(b) The ambient temperature within the product enclosure should be increased uniformly at a rate not exceeding 40 F per hr. (If plant production procedures require early application of steam, the rate of temperature rise should be restricted to less than 20 F per hr.) Due to the slow rise of ambient temperature with radiant heat, application of heat cycle may be accelerated to meet climatic conditions. However, in all cases, the curing procedure to be used should be well established and carefully controlled.

(c) The optimum curing temperature is from 140 F to 160 F. In no case should the curing temperature exceed 175 F as higher temperatures may have a detrimental effect on strength. Duration of heat curing should be dictated by strength requirements for stripping as measured by test cylinders cured with the products. Caution should also be exercised when infra-red lamps are used. Localized "hot areas" must be avoided.

(d) For units with a smooth finish, the ambient temperature within the product enclosure should be decreased at a rate not to exceed 60 F per hr. until this temperature has reached 80 F in order to prevent surface crazing.

(e) Recording thermometers showing the time-temperature relation throughout the period from placing of concrete to stripping should be provided. To aid personnel who control the temperature during curing, it is recommended that the desired curing time-temperature relations be placed on the chart of the recording thermometer. With this information available, the desired temperature may be more easily maintained.

Curing procedures should be determined on an experimental basis and are most important, since they fix the total curing time within the 24-hr. cycle essential to economic production.

Proper precautions should be taken with accelerated curing of units using surface retarders to make certain that the proper retarder is selected and that retardation is uniform and effective at time of stripping and treating the surface.

Units should be allowed to cool gradually to prevent thermal shock and rapid temperature changes, which may cause cracking. When the concrete is warmer than the air during cold weather, there is a tendency for soluble salts (effloresence) to migrate to the surface immediately on stripping. In addition, cool water should not be used to accomplish aggregate exposure until the unit has cooled to ambient temperature.

5.5.7—Handling

Lifting heavy units from threaded inserts should be carefully assessed. When properly designed (for insert and concrete strength) and applied according to such criteria, threaded inserts have many advantages. Correct usage is sometimes difficult to inspect during handling operations. Insufficient threading, wrong alignment of pull, even worn threads or low concrete strengths have been frequent errors.

Section 6—Concrete Finishes

5.6.1—General

Many finishes cannot be achieved with equal visual quality on all faces of the unit. The reason for this comprises several factors such as mix proportions, variable depths (and pressures) of concrete, and small differences in consolidation techniques, particularly in the case of intricate shapes with complex flow of concrete. The effect of gravity during consolidation forces the larger aggregates to the bottom and the smaller aggregates, plus the sand and cement content, upwards. Consequently, the down-face in the mold will nearly always be the most uniform and dense surface of the unit.

in exposure between the down-face and returns in exposed aggregate surfaces. Emphasis should be placed on choosing suitable concrete mixes with aggregates which are reasonably spherical or cubical to minimize differences. For large returns, or situations where it is necessary to minimize variations in appearance, concrete mixes should be selected where the aggregate gradation can be uniformly controlled and preferably fully graded. Exposures should be medium to deep and color differences between the ingredients of the mix should be minimal.

Panels with large returns also may be cast in separate pieces and joined with dry joints. This enables all faces to be cast with the same orientation. If this is the indicated production method, attention must be paid to suitable fillets and reinforcement at the corners, and a groove or architectural feature should be incorporated at the dry joint. Although the dry joint may not show with certain mixes and textures, a groove will certainly help to mask it.

It must be recognized that some blemishes or variations in color occur in architectural concrete work. For example, panels containing aggregates and matrices of contrasting colors will appear less uniform than those containing materials of similar colors. Further, form-finished panels may appear less uniform in color than the same units subsequently given an exposed aggregate finish. Uniformity in color, even within small panels finished with black coloring, and for panels using gray or buff cement, may vary from panel to panel. The color of precast concrete can vary between adjacent elements due to the variations in the water-cement ratio and curing conditions for the concrete. Buff color achieved with fine aggregate is more easily controlled even in combination with gray cement. Further, where fabrication has had to continue over extended periods, color can vary because of the variance in the physical characteristics of cements, coarse aggregates and sands, even though they may be from the same sources. Crazing tendencies may occur in some smooth finishes. As a general rule, a textured surface is esthetically more satisfactory than a smooth surface because the texture of the surface to a very large extent camouflages subtle differences in texture and color of the concrete.

A stippled concrete finish should be used if the surface is to be painted. This is accomplished with a roller following strike-off and wood float finishing. For panel backs which are to receive insulation, the need for smoothness of the finish will depend on the insulation. It should normally be as smooth as a good wood float finish.

Aggregate transparency is a condition in which the formed concrete surface is marked by dark areas similar in size and shape to particles of coarse aggregate in the concrete mix. When encountered, it usually appears on smooth surfaces.

Aggregate transparency is assumed to be caused by localized segregation during compaction of concrete. As concrete is vibrated, particles of coarse aggregate near the form face tend to move slightly from it. Fine material simultaneously fills the area between each coarse particle and the face of the form. The movement is, however, very small so that only the finest of the mortar components can flow in this way. This means that at the completion of vibration the area between the coarse aggregate particle and the face of the form will be filled with a fine mortar, which is rich in cement. Such localized segregation occurs at all formed surfaces, but apparently the smooth surface areas are coated with highly oriented calcium hydroxide crystals that are translucent and transmit the hue of the underlying aggregate particles.

The remedy for white concrete would be to wash the surface with a 2 to 3 percent phosphoric acid solution to disrupt the calcium hydroxide surface layer. Alternate wetting and drying of the surface would with time also allow the calcium hydroxide crystals to dissolve and carbonate. Minimal wetting is required to ensure that the calcium carbonate crystals formed remain on the surface. The surface becomes uniformly white when sufficient carbonate is deposited. Normal weathering may also produce sufficient carbonation to bring the concrete color to acceptable uniformity.

Another way to stop translucent blemishes is to use an appropriate release agent. To obtain the whitest most uniform surface, a release agent that causes a matte surface should be used. The harder, non-dusting surfaces given by some release agents are usually more discolored.

5.6.5—Sand or Abrasive Blasting

For deep exposure with a sandblasted appearance, retarders or face-up water washing may be used initially followed by sandblasting. Extra care should be taken to avoid non-uniform exposure that may be caused by the presence of soft and hard spots on the retarded surface. This is especially true and more noticeable on large flat surfaces. Small flat areas or surfaces that are divided by means of rustications will tend to call less attention to these texture variations.

The degree of uniformity obtainable in a sandblasted finish is generally in direct proportion to the depth of sandblasting. A light sandblasting may look acceptable on a small sample, but uniformity is rather difficult to achieve in reality. The lighter the sandblasting, the more critical the skill of the operator, particularly if the units are sculptured. Small variances in concrete strength at time of air holes on the returns which might show strongly in a light sandblasted texture. If such air holes are of a reasonable size, 1/8 to 3/16 in., it is strongly recommended that they be accepted as part of the texture because filling and sack-rubbing is expensive and may cause color differences. To improve uniformity, but at increased cost, the light sandblast finish may be obtained by blasting with materials softer than silica sand.

The objective of a brush-blast, which is little more than a uniform scour cleaning that lightly textures the surface skin, is to remove minor surface variations. A brush-blast surface seldom appears uniform at close inspection and should be viewed at a distance for uniformity.

A good general rule in selecting an abrasive is that the particle size of the abrasive will attack a similar size particle in the concrete surface. Because of this, when the goal is a lightly blasted or flat surface, a medium or coarse gradation in the abrasive should be selected. This size abrasive has a tendency to pound the concrete surface and remove the surface skin without digging into the finer mortar. For a deep exposure of the coarse aggregate, a finer abrasive should be used because the finer abrasive attacks the smaller particles in the mortar fraction of the concrete without affecting the coarse aggregate as much.

For cleaning or light blasting of a surface, any of the abrasives will be adequate. For deep cutting, an abrasive grit should be used because of its speed of attack and cleaner surface appearance produced.

The abrasive may be reclaimed and cleaned depending on the economies involved. Each time the abrasive is reused, it becomes finer, dustier, and more inefficient. Thus, after recovery, an effective separation system is necessary. Grasping a handful of abrasive and letting it spill from the side of the hand is a rough means of discovering any large amount of fines.

Sandblasting may be done with dry abrasive in a stream of compressed air or water rings may be used to introduce water into the compressed air-sand stream at the nozzle. Sand also may be introduced into a high pressure water washer.

The compressor characteristics will influence both the speed and quality of the work. Rotary or screw type units deliver constant pressure but piston units cause air flow to fluctuate and make it difficult for the nozzleman to produce a uniform surface. The longer the hose, the higher the pressure needed at the pot to overcome pressure losses in the line. In light blast finishes, 70 to 80 psi pressure at the nozzle is usually sufficient. Heavy blast textures require up to 120 psi. The compressor should have a capacity of at least 200 cu. ft. per min.

The nozzle at the end of the system is the most important element. A Venturi nozzle should be used to obtain a uniform impact pattern. Carbide or norbide nozzles should be selected for durability. Small and lightly blasted jobs require a minimum ⅜-in. orifice while a ¾-in. orifice can give considerably more production on a larger surface. Nozzle life depends on abrasive hardness and volume as well as the pressure and generally varies from 2 to 4 months.

The sand pot should be of 300- to 500-lb. capacity with properly functioning moisture separator and abrasive flow controls. The hose and pot internal tubing should be properly sized and balanced.

The time when sandblasting should take place is determined by scheduling, economics, visual appearance desired, and hardness of the aggregate. The timing of blasting is not as critical as for other methods. The concrete matrix will be easier to cut in the first 24 to 72 hrs. after casting. As the concrete cures and gains strength, it becomes more difficult to blast to any appreciable depth, thus increasing the cost of the operation. Softer aggregates tend to abrade more when concrete strengths are high and surface will have a duller appearance. In some cases, the higher costs of deferred blasting may be justified by avoiding scheduling problems. However, all surfaces should be blasted at approximately the same age or compressive strength for uniformity of appearance. The concrete mix used, and the matrix strength at time of blasting, will affect the final exposure, as will the gradation and hardness of the abrasive.

Degrees of exposure vary according to the angle at which the nozzle is aimed and the distance from the nozzle to the surface. When blasting, the operator should hold the nozzle perpendicular to the surface on which he is working. Some operators will deviate slightly from this position as it seems to provide a better view of the work. The maximum deviation should be less than 15 deg. as too much deviation from the 90-deg. angle will result in undercutting the coarse aggregate particles. Best results are obtained with the nozzle positioned from about 2 to 5 ft. from the element surface. The exact distance depends on the pressure used, the hardness of the concrete matrix, and the cutting ability of the abrasive. An experienced operator can quickly determine the nozzle position to produce the specified surface finish.

When using wet sandblasting, the abraded mortar should be continually washed off previously sandblasted areas to prevent staining.

Wood liners, either as boards, plywood panels, or nailed-on inserts, work well. Wood liner surfaces should be sealed to prevent surface discoloration of concrete caused by differential absorption of liner. Then the liner should be lightly coated with form oil prior to casting. Sandblasted wood, textured plywood and rough-sawn lumber are useful in creating rugged textures. Rough-sawn lumber is often used for board surface textured finishes where concrete color variations are acceptable. Absorption can be minimized by coating the lumber with a wood sealer. To prevent bowing of the boards, all sides can be coated with wood sealer by painting or immersing. Even with a sealer, some types of lumber may absorb moisture from the concrete. In other cases, natural sugars found in the lumber, such as pine, may penetrate the sealer coating when concrete is cast against the form, retard the set of the cement at the surface and cause a dusty, dark, blotchy effect. Fir is the preferred choice for board surface finishes due to its low sugar content.

The weathering of the lumber can also affect the outcome of the concrete finish. If rough sawn lumber is being used, it is important to cast samples to determine the effect the lumber will produce. The lumber selected should be purchased all at one time from one source to minimize the possibility of variations. Moisture leakage between pieces of lumber should be prevented or a dark line will result from the change in water-cement ratio. The joints may be sealed by using tongue-and-groove lumber. Closed-cell gasket material should be used at edges of form to prevent leakage.

Metal liners are available in various textures that can be combined with different types of fasteners to achieve an architectural effect. Liner joints should be at rustication strips or form edges since leakage is difficult to prevent at butt joints. Investigation should be made to determine whether staining may occur from the liner material or its fastenings.

Elastomeric materials should have a Shore A-2 hardness of 50 to 60 and a minimum ultimate tensile strength of 600 psi. Elastomeric and rubber liners display gasketing characteristics and therefore achieve weep-free seamless joints. They also eliminate the need to cover the small slits cut in the liner for the roofing nails. Elastomeric form liners may ripple unless there is a good bond to the base form. It may be desirable to have the product delivered with a plywood backing already attached. Edges of liners should be sealed to each other or to divider strips to prevent bleeding of grout. The sealant used should be non-staining to the surface. Because of the difficulty in matching joints between liners, this technique should be limited to widths less than the available width of the liner, or joints should be detailed as an architectural feature in the form of a groove, recess or rib.

Plastics can be obtained in sheet form with smooth or textured surfaces. These may be thermoformed or extruded ABS plastic, fiberglass reinforced plastic, or polyvinyl chloride liners. Sheet plastics may need appropriate backup to resist the concrete pressure, particularly for wide portions of liners with deep indentations.

Foamed plastics create deeply revealed designs or blockouts. The preformed foam planks are easily cut to size, easily attached to the form, and are inexpensive enough not to require salvaging. It is necessary to use a low solvent contact glue which should dry before contact with foam plastic is made or the solvent will dissolve the plastic. Foam plastic is also used in backing for thick, vacuum-formed, plastic form liners where the concrete pressure would cause deformation of otherwise unsupported recess forms.

Rubber liners are useful for detailed textured surfaces and will greatly facilitate stripping, whereas other materials for such detail would be virtually impossible to strip. The rubber should be checked for resistance to deterioration by oils commonly used as parting agents and rigidity sufficient to resist wrinkling. The rubber should also be checked for the possibility of staining or discoloring the concrete. Trials should also be made to determine the best time for stripping so the surface remains intact and the liners can be reused.

Combination finishes involving the use of more than one basic finishing method are almost infinite. One common example is the ribbed form liner and sandblasted finish.

5.6.7—Tooled or Bushhammered

As a cutting head becomes worn, it should be replaced. Since the texture varies with the condition of the cutting surface, a new head should not be worked next to an area tooled with an old one. Small irregularities in the finished surface can be worked out with further tooling.

Orientation of equipment and direction of movement for tooling should be kept uniform throughout the architectural work as the tooling process produces a definite pattern on the surface. Care should be exercised to avoid exerting excessive pressure on the tool, especially when starting, so as not to remove more material than either necessary or desirable.

Bushhammering at corners tends to cause jagged edges. If sharp corners are desired, bushhammering should be held back from the corner a distance of 1 to 2 in. If areas near corners are ners are best with this type of treatment.

A hammered rib (or fractured fin) finish may be produced by casting ribs in concrete and then using a 3-lb. hammer to break the ribs. The effect is bold and deeply textured. Uniformity of cleavage may be obtained by alternately striking opposite sides of the flute.

Tooling removes a certain thickness of material—$\frac{3}{16}$ in. on an average—from the surface of the concrete and may fracture particles of aggregate causing moisture to penetrate the depth of the aggregate particle. For this reason the minimum cover to the reinforcement should be somewhat greater than normally required. It is sometimes recommended that 2 in. of cover be provided (prior to tooling).

5.6.8—Acid-Etched

Normally, a given amount of acid will react with a certain amount of cement no matter how much water is used to dilute it. For example, the theoretical amount of 37 percent hydrochloric acid (reagent grade) required to etch a 6-bag concrete to a depth of $\frac{1}{32}$ in. is 0.015 gal. per sq. ft. This means that 1 gal. would etch 65 sq. ft. if there were no losses by evaporation and spillage and if none of the aggregate reacted with the acid. A lot of water will reduce the reaction speed although a small dilution might increase it slightly. The acid should be agitated and/or treated to improve its effectiveness. The rate of reaction will approximately double for each 20 F increase in temperature. High temperature, however, causes hydrogen chloride to escape from solution faster producing two undesirable effects: (1) loss of some of the acid that would otherwise be put to work and (2) contamination of the atmosphere. If adequate ventilation is available and if time is more important than material, these may not be serious objections.

DIVISION VI—TRANSPORTATION AND ERECTION

Section 2—Procedures

6.2.1—Handling

Where handling stresses are determined by structural analysis, positions for support and handling may be varied subject to maintenance of stresses within applicable design values. For most architectural concrete units, vertical handling and two-point support should be the rule. However, many units are of a size or shape that alternate methods have to be applied. For unsymmetrical units or units of unusual section, it is particularly necessary that handling stresses be computed including adequate provision for impact (normally 50 to 100 percent), and positions and details of handling devices be shown on erection drawings.

6.2.2—Loading and Delivery

The manufacturer should ensure that all units are satisfactory for delivery before scheduling loading. This may necessitate a lead time for final checking, possible cleaning and minor repairing that may be required as a result of damage or accumulation of dirt in storage. Units should not be shipped to jobsites until they have reached sufficient strength to withstand the effects of the particular shipping and handling methods used.

Factors such as the size, shape, type of finish, type of aggregate, method of transportation, type of vehicle, weather and road conditions, and distance of haul enter into determining the necessity of wrapping or protecting the precast unit during shipment.

Flatbed or low-boy trailers suffer excessive distortions during hauling. Thus, support at more than two points on a trailer unit can be achieved only after considerable modification of the trailer. Transporting vehicles should not cause impact loads on precast units by driving over bumps, drop-offs, or holes.

Delivery of units should be scheduled such that erection may be accomplished directly from the delivery vehicle. This procedure eliminates jobsite storage, lowers cost, and reduces the chance of damage by eliminating extra handling.

Corners and units with returns of unusual lengths are often shipped with edge-to-edge bracing which should not be removed until just prior to erection.

There are a variety of ways by which a unit may be hoisted into position. The type of erecting equipment is determined by the weight of the product and distance of reach to set the unit. Whether the unit is slowly picked off the truck or turned in the air is determined by the limitations the unit poses to handling.

be picked up in the same position and tilted to a vertical standing position by using two falls, carefully avoiding tipping or twisting during this operation. Long members should be hoisted by two cranes or, if this is not necessary from a capacity viewpoint, then by one crane using two falls by which the members can be picked up in a horizontal position and gradually tilted into a vertical position for installation. For unusually shaped units, special erection rigs, such as rotating sheaves, spreader beams or specially designed equipment, should be used to avoid damaging the units during hoisting and installation.

6.2.3—Erection

Stacking of units with temporary erection shims is sometimes an erection procedure with precast concrete. Unless such temporary loading of units has been specifically incorporated or allowed in the contract documents, it is recommended that the erector be responsible for this temporary loading of the units. Lead, plastic or asbestos-cement spacing shims may be used to attain the specified joint dimension. Shims should be placed near the back of the unit to prevent spalling of the face in case of excessive loading. Shims should be removed from joints of non-load bearing units after connections are completed and before applying sealant.

For load bearing units, the use of non-metallic shims or bearing pads such as neoprene or plastic is advantageous where bearing pressures do not exceed the allowable concrete stresses, and the potential risk of damage to concrete edges is negligible. They should be recessed out of view as they can be unsightly and difficult to remove if exposed to view.

All temporary lifting and handling devices cast into the precast concrete elements should be dealt with as specified on the erection drawings based on one or more of the following conditions:

(1) Removed where they interfere with other trades.
(2) Removed and surfaces repaired where demanded by appearance requirements.
(3) Removed or protected from possible corrosion and marring of the finished product.
(4) Coated for protection against possible corrosion.
(5) No action required.

When the temporary lifting and handling devices are located in finished edges or exposed surfaces, bolt or insert holes require filling and repairing by the erector. When this is necessary, it is recommended that the Architect-Engineer approve the insert locations and procedures on the erection drawings. If necessary, these devices may be recessed, filled, and finished at a later date. Repairs should be properly executed in accordance with Article 2.4.2 and should be subject to the Architect-Engineer's acceptance.

As with considerations for production, the connection details should be as standardized as possible. Repetition of the same connection improves quality control in the field, which leads to better structural performance. A major advantage of standardized connections is that when erectors understand and have experience with a typical connection, they are in a better position to expedite proper placement and connection of the members as erection progresses. In general, heavier hardware should be used at lightly loaded units if it will eliminate a special piece mark and result in only slightly more material. This practice prevents the possibility of the smaller piece being used where the heavy one is required.

Standardization also applies to dimensioning of connection details. Little is gained by slight changes in dimensions, since the savings in materials may be more than offset by the extra labor involved in developing the modifications. Furthermore, if the different connections vary only slightly in dimensions, there is a greater chance that an improper connection may be used at a given location.

Standardization can be used in still another context. With rare exception, all the items, materials and procedures involved in making connections should be standard to the industry and readily available. It is generally more practical to use additional quantities and even more expensive materials to achieve this type of standardization than to select items or materials that may result in delay of production or may be unfamiliar to the trade.

Because welding creates heat and expansion in metal, the anchorage of hardware may be endangered, or the concrete may spall or crack in the vicinity of this metal, in particular where the expansion of the heated metal is restrained by concrete. For this reason, hardware directly attached to, or embedded in concrete should normally have a minimum thickness of $^{3}/_{8}$ in. if welding is required. It may be desirable to line the metal with sealing foam, clay, or other materials to minimize the risk of the concrete cracking, especially if the metal is thinner than $^{3}/_{8}$ in.

The amount and quality of weld must be controlled, as excessive continuous welds can be detrimental to the panel and to the connection. Long welds should be made in stages or designed as intermittent welds.

When selecting the type of connection to be used, it is desirable to eliminate welded connections if temperatures below 20 F are likely at the time of erection because of the possibility of fractured welds.

Bolting generally permits an initial connection to be made with

If forced, this will cause spalling on the unit face. If the hole is too deep, there is a possibility that the threads of the bolt will not reach the threads of the insert cast into the unit. A bolt that is too long should be shimmed, one too short should be replaced with a longer one.

Regardless of the load requirements, a ½-in. diameter bolt should be the minimum size used for any precast concrete connection. It is equally important to consider the types of threads being used in bolted connections and to select those that are considered to be standard.

Connections may have to be protected from corrosion depending on exposure conditions. The most common condition requiring protection is exposure to climatic conditions. All connection hardware needs special protection against humidity or corrosive environment.

Protection may be:

(1) Paint with shop primer.
(2) Coating with zinc-rich paint.
(3) Zinc metallizing.
(4) Cadmium plating.
(5) Hot dip galvanizing (if connection hardware must be galvanized do so following fabrication).
(6) Use of stainless steel for connections.

The cost of protection increases in the order of listing. Proper cleaning of hardware prior to protection treatment as listed in Items (1) to (3) is most important. See Article 4.2.3 for additional discussion of corrosion protection.

Apart from base plates for load bearing units, grouting or drypacking of connections is not widely used because of the uncertainty of predicting load distribution. Difficulty in maintaining exact elevations, and the inability to allow movements and still maintain weather-tightness must also be considered. Grout should be carefully used when installed during temperatures below or near freezing. Grouting may be used where the above drawbacks do not exist or where the timing of the grouting and/or its exposure is not critical.

For dowelled and grouted connections, grout holes should be grouted just prior to setting precast panels. Grout consistency should permit displacement of some grout when the panel is placed. Where grout beds are required, the units may be set on shims and drypacked at a later date, or by the units may be set into fresh grout with the elevation controlled by shims and the excess grout removed.

Rain water or water from hoses used during the construction of the building, can cause discoloration of the precast units by washing across building materials (such as steel, concrete, or wood) and then across the units. Particular care should be taken to avoid washing of the units by jobsite water.

6.2.4—Tolerances for Erection

If reasonable tolerances and adjustments have been designed into the construction details and complied with, the erector should be able to:

(1) Avoid joint irregularities such as tapered joints (panel edges not parallel), jogs at intersections, and nonuniformity of joint width.
(2) Maintain proper opening dimensions.
(3) Properly execute all fastening connections.
(4) Align the vertical of the units to avoid "offsets."
(5) Prevent the accumulation of tolerances.

A more precise installation and general improvement in appearance is then achieved.

Erection tolerances are of necessity largely determined by the actual alignment and dimensional accuracy of the building frame. The General Contractor is responsible for the plumbness, level and alignment of the structural frame including the location of all bearing surfaces and anchorages for precast products. There are many Architect-Engineers who fail to recognize the critical importance of controlling building frame tolerances. It is not uncommon to find specifications in which no mention is made of the tolerance to be held in the structure to which the precast components is being connected, and clearance dimensions shown on the drawings which allow for no tolerance at all. If the precast units are to be installed reasonably "plumb, square, and true," the actual location of all surfaces affecting its alignment, including the levels of floor slabs and beams, the vertical alignment of floor slab edges and the plumbness of columns or walls must be known before erection begins.

The Architect-Engineer, in his specifications, should clearly define the maximum tolerances to be permitted in the building frame alignment, then should see that the General Contractor frequently checks to verify that these tolerances are being held. Lack of attention to these matters often necessitates changes and adjustments in the field, not only delaying the work but usually resulting in unnecessary extra costs, and sometimes impairing the appearance of the units and completed structure.

Tolerances of the building frame must be adequate to prevent obstructions that may cause difficulty with or hinder panel installation procedures. The structural frame also should provide for beam elevations and column locations should be uniform in relation to the precast units with a constant clear distance between the precast concrete and support elements.

For a cast-in-place concrete frame, the maximum tolerances that should be permitted, unless otherwise specifically stated in the specifications, are those given in Section 2.4.1 of the American Concrete Institute *Recommended Practice for Concrete Formwork* (ACI 347–68) or in Table 4.3.1 in *Specifications for Structural Concrete for Buildings* (ACI 301–72) (Revised 1975). These tolerances are quite optimistic for tall buildings when one compares them to AISC tolerances and to tolerances actually obtained on concrete buildings. Also, greater variations in height of floors are more prevalent in cast-in-place structures than in other structural frames. This will affect location or mating of the insert in the panel with the cast-in connection device. Tolerances for cast-in-place structures may have to be increased further to reflect local trade practices, the complexity of the structure, and climatic conditions. Also, the stated cast-in-place tolerances are difficult to attain during severe winter conditions.

The following tolerances, in addition to ACI 301 or ACI 347 requirements, should be specified for cast-in-place concrete when precast concrete units are to be connected:

(1) Footings, caisson caps, and pile caps
  (a) Variation of bearing surface from specified elevation: ½± in.
(2) Piers, columns, and walls
  (a) Deviation in plan from straight lines parallel to specified linear building lines:
    1/40 in. per ft. adjacent members less than 20 ft. apart or any wall or bay length less than 20 ft.
    ½ in. adjacent members 20 ft. or more apart or any wall or bay length of 20 ft. or more.
  (b) Deviation in elevation from lines parallel to specified grade lines:
    1/40 in. per ft. adjacent members less than 20 ft. apart or any wall or bay length less than 20 ft.
    ½ in. adjacent members 20 ft. or more apart or any wall or bay length of 20 ft. or more.
(3) Anchor bolts
  (a) Variations from specified location in plan: ±¼ in.
  (b) Variation from specified elevation: ±½ in.
  (c) Anchor bolt projection: −¼ in. +½ in.
  (d) Plumbness of anchor bolts: ±1/16 in.

Tolerances for structural steel framing should be specified to conform with the American Institute of Steel Construction (AISC) *Code of Standard Practice for Steel Buildings and Bridges*, Section 7.11. Particular attention is directed to the "Commentary" included in the latest (September 1, 1976) edition of this Code, which provides a detailed explanation of the specified erection tolerances. Mill, fabrication and erection tolerances combined result in the final accuracy of the structural steel frame.

In the determination of tolerances, attention should also be given to deflections and/or rotations of structural members supporting precast concrete. This is particularly important for bearing on slender or cantilevered structural members. If the deflection of the frame is sensitive to the location or eccentricity of the connection, limits should be given. Consideration should be given to both initial deflection and to long-term deflections caused by plastic flow (creep) of the supporting structural members.

A structural steel frame building presents different erection and connection problems from the concrete frame building. For example, structural steel, being relatively weak in torsion, compared to concrete, generally requires that the load be applied directly over the web or that the connection be capable of supporting the induced moment. This in turn can place a greater structural requirement on the connection, as well as creating problems during erection if any rolling behavior of the steel beam occurs. Also, when detailing precast units for attachment to steel structures, allowance must be made for sway in tall, slender steel structures with uneven loading, and movements due to sun or wind on one side or seasonal thermal expansions and contractions.

The allowable tolerances for steel frame structures make it impractical to maintain precast concrete panels in a true vertical plane. Based on the allowable steel frame tolerances it would be necessary to provide for a 3 in. adjustment in connections up to the 20th story and a 5 in. adjustment in connections above the 20th story if the Architect-Engineer insists on a true vertical plane. These adjustments in connections are not economically feasible, therefore precast concrete walls should follow the steel frame.

It should also be recognized that ACI 301 applies only to reinforced concrete buildings, and the AISC Code only to steel building frames. Neither of these standards applies to buildings of composite construction (e.g., concrete floor slabs carried by steel columns or to concrete encased structural steel members, or fireproofed frames). Obviously, the location of the face of the fireproofing on the steel, as well as that of the steel member itself, are both critical. As the alignment of composite members, fireproofing and masonry work are not controlled by referencing these standards, the Architect-Engineer should require that the location of all tolerances which are, at most, no more than those specified in ACI 301. Should there be some doubt as to what these tolerances should be, the precast manufacturer should be consulted for advice.

The variations permitted for horizontal and vertical building lines and for placement of footings should not be construed to permit encroachment of a building beyond its legal boundaries.

With reasonable tolerances for the building frame established, it is equally important that the designer provide proper clearances (purposely provided space between adjacent parts) between the theoretical face of the structure and the back face of precast units in detailing the wall and its relation to the building structure. Otherwise, alignment of the wall as specified will likely necessitate delays and extra costs, or may even be impossible.

The failure to provide adequate clearances is an all-too-common deficiency of wall designs. They are absolutely essential for any of several reasons: (1) to accommodate movement between adjacent parts; (2) to provide for possible size variations and misalignment; or (3) to provide working space to make the connection. Sufficient room for welding or adequate space to place a wrench to tighten a bolt must be provided. When erecting the wall it is the latter two reasons that are of prime concern.

The clearance necessary for erection of a wall will depend on the wall design, the dimensional accuracy of the building frame or other construction to which the wall is connected and the limits of adjustment permitted by the connection details. If a connection is required to the face of spandrel beams or columns or their fireproofing, more clearance will be needed to install fastenings than when the anchors are located on the top face of beams and the sides of columns.

A good rule of thumb is that at least ½ in. clearance be required between panels and precast members; 1 in. is the minimum tolerable clearance between any cast-in-place concrete with 1½ in. preferred; and 1 in. is the minimum clearance required for a steel frame structure. At least 1½ to 2 in. clearance should be allowed in tall, irregular structures regardless of the structural framing materials. The minimum clearance between column covers and column is 1½ in.; 3 in. is preferred because of the possibility of columns being out of plumb or dimension causing interference with completion of the connection. If clearances are realistically assessed, they will solve many tolerance problems. Where large tolerances have been allowed for a supporting structure or where no tolerances are given, the clearance must be increased.

The nominal clearance dimension shown on the drawings should be equal to the actual clearance required plus the outward tolerance permitted for the adjacent construction, and should be determined on the assumption that this construction will be as far out of position in the wrong direction as is allowed. Connections should be designed to accommodate the clearance plus the inward tolerance also.

The maximum variation from the specified clearance between adjacent independent members of separated building parts or components should be ±¼ in. Adjacent independent members are members that are close together but are not connected structurally. These members may both be precast concrete or they may be combinations of precast concrete and cast-in-place concrete, masonry, or steel. Typically, this clearance situation develops at an expansion joint or at the interface between a stair tower and a larger structure when the two are joined only by an expansion joint.

All connections should be provided with the maximum adjustability that is structurally or architecturally feasible. Where a 1-in. tolerance is indicated but a 2-in. tolerance creates no structural or architectural problems, the 2-in tolerance should be selected. Closer tolerances are required for bolted connections than for grouted connections. Connections should provide for vertical, horizontal and lateral adjustments of at least 1 in. to accommodate any misalignment of the building frame. Location of hardware items cast into, or fastened to the structure by the General Contactor, steel fabricator or other trades should be determined with specified tolerances for placement. Unless some other value is specified by the Architect-Engineer, tolerances for such locating dimensions should be 1 in. in all directions (vertical and horizontal), plus a slope deviation of no more than ±¼ in. for the level of critical bearing surfaces. For smaller and simpler structures, location tolerances of ±½ in. may be feasible. Complicated structures should allow 1 in. for accuracy of location. Connection details should consider the possibility of bearing surfaces being misaligned or warped from the desired plane. Adjustments can be provided by the use of dry-pack concrete, non-shrink grout, or elastomeric pads if the misalignment from the horizontal plane does not exceed ±¼ in.

Where possible, connections should be dimensioned to the nearest ments affecting structural performance, other than adjustments within the prescribed tolerances, should only be made after approval by the design engineer.

The precast units should be located in the center of their theoretical location on the structure and adjusted to accommodate adjacent products, proper joint width, and alignment with adjacent precast products. Small width variations between adjacent joints can be achieved by setting out joint centerlines equally spaced along an elevation and centering units between them. The alignment for exterior units should be assumed to be the outside face unless the inside face is so specified. Variations from true length or width dimensions of the overall structure are normally accommodated in the joints or, where this is not feasible or desirable, at the corner units, in expansion joints, or in joints adjacent to other wall materials.

A liberal joint width should be allowed if variations in overall building dimensions are to be absorbed in the joints. This may be coupled with a closer tolerance for variations from one joint to the next for appearance purposes. It is apparent that the individual joint width tolerance should relate to the number of joints over a given building dimension. For example, to accommodate reasonable variations in actual site dimensions, a ¾-in. joint may be specified with a tolerance of ±¼ in. but with only a $\frac{3}{16}$-in. differential variation allowed between joint widths on any one floor, or between adjacent floors. Alternatively, the jog in alignment of edge may be specified.

In a situation where a joint has to match an architectural feature (such as false joints), a large variation from the theoretical joint width may not be acceptable and tolerances for building lengths will have to be accommodated at the corner units.

6.2.6—Cleaning

It may be necessary to remove efflorescence, a common phenomenon, which often occurs to various degrees on all concrete surfaces. Efflorescence is a crystalline deposit of salts, usually white in color, caused by soluble alkalies that migrate to the concrete surfaces with evaporating water. Discoloration may occur, but this usually is temporary. Dark surfaces tend to multiply the unsightliness of efflorescence that might not otherwise be seen on a light or whitish background. It occurs most frequently during the winter months when a slower rate of evaporation due to low temperatures and high relative humidities allows excessive migration of the salts to the surface.

It is important, whenever a cleaning compound or acid solution is used, that the areas to be cleaned are thoroughly dampened with clean water prior to application of the cleaning material to prevent the cleaning solution from being absorbed deeply into the surface. The cleaned area should be thoroughly rinsed with clean water. Cleaning solutions *should not be allowed to dry* on the concrete finish.

Since the use of a dilute solution of muriatic acid, 5 to 10 percent, may slightly change the appearance of the finish, the entire wall should be treated to avoid a discoloration or mottled effect. A more dilute solution (2 percent) may be necessary to prevent surface etching that may reveal the aggregate and change colors and textures. Hydrochloric (muriatic) acid may leave a yellow stain on white concrete and therefore 3 percent phosphoric acid is preferable on white concrete.

6.2.7—Clear Surface Coatings

The effectiveness of sealers depends on the qualities of specific sealers. Some problems that have occurred with certain sealers are:

(1) Appearance changes vary with the age of the panel being treated. Normally the panel will take on a "wet" look. Some sealers may create a blotchy appearance if applied before panels are fully cured and dried, while others may be less effective in time if sealers are applied too early.

(2) Certain sealers such as silicones have been found to attract air-borne hydrocarbons.

(3) Sealers or clear surface coatings will often interfere with patching and adhesion of joint sealants. Application of these sealers should therefore be delayed until these operations are completed. Sealers may also accentuate a patched area of different density.

(4) Life expectancy, the possibility of severe and permanent discoloration of the concrete surfaces to various shades of yellow, brown or gray, and peeling vary considerably between types and sources of sealers.

(5) Proper application following manufacturer's instructions depends on qualified operators and sometimes expensive pretreatment of precast units.

The type of solvent used, as well as the solids, can affect the resulting color of the concrete surface so neither the type nor source of sealer should be changed during the life of a project. Generally, the products having higher solid content tend to produce darker surfaces with glossy effects. The amount of color change depends on the materials in the sealer and their reaction with the materials should have a high viscosity and high solids content.

Generally, good airless spray equipment should be used to apply the sealer uniformly on the surface and prevent surface rundown. Two coats are usually required to provide a uniform coating, because the first coating is absorbed into the concrete. The second coat does not penetrate as much and provides a more uniform surface color.